MOLESWORTH'S
POCKET BOOK OF
ENGINEERING FORMULÆ

agx

1890	Sunday.	Monday.	Tuesday.	Wed'day.	Thursday	Friday.	Saturday.
Jan.	..	..	..	1	2	3	4
	5	6	7	8	9	10	11
	12	13	14	15	16	17	18
	19	20	21	22	23	24	25
	26	27	28	29	30	31	..
Feb.	..	..	..	..	..	..	1
	2	3	4	5	6	7	8
	9	10	11	12	13	14	15
	16	17	18	19	20	21	22
	23	24	25	26	27	28	..
Mar.	..	..	..	..	..	..	1
	2	3	4	5	6	7	8
	9	10	11	12	13	14	15
	16	17	18	19	20	21	22
	23	24	25	26	27	28	29
	30	31	..	..	..	..	..
Apr.	..	..	1	2	3	4	5
	6	7	8	9	10	11	12
	13	14	15	16	17	18	19
	20	21	22	23	24	25	26
	27	28	29	30	..	..	..
May	..	..	..	..	1	2	3
	4	5	6	7	8	9	10
	11	12	13	14	15	16	17
	18	19	20	21	22	23	24
	25	26	27	28	29	30	31
	..	..	..	..	..	..	..
June	1	2	3	4	5	6	7
	8	9	10	11	12	13	14
	15	16	17	18	19	20	21
	22	23	24	25	26	27	28
	29	30	..	..	..	..	..

1890	Sunday.	Monday.	Tuesday.	Wed'day.	Thursday	Friday.	Saturday.
July	..	..	1	2	3	4	5
	6	7	8	9	10	11	12
	13	14	15	16	17	18	19
	20	21	22	23	24	25	26
	27	28	29	30	31	..	..
Aug.	..	..	..	..	..	1	2
	3	4	5	6	7	8	9
	10	11	12	13	14	15	16
	17	18	19	20	21	22	23
	24	25	26	27	28	29	30
	31	..	..	..	..	..	..
Sep.	..	1	2	3	4	5	6
	7	8	9	10	11	12	13
	14	15	16	17	18	19	20
	21	22	23	24	25	26	27
	28	29	30	..	..	..	..
Oct.	..	..	..	1	2	3	4
	5	6	7	8	9	10	11
	12	13	14	15	16	17	18
	19	20	21	22	23	24	25
	26	27	28	29	30	31	..
Nov.	..	..	..	..	..	..	1
	2	3	4	5	6	7	8
	9	10	11	12	13	14	15
	16	17	18	19	20	21	22
	23	24	25	26	27	28	29
	30	..	..	..	..	..	..
Dec.	..	1	2	3	4	5	6
	7	8	9	10	11	12	13
	14	15	16	17	18	19	20
	21	22	23	24	25	26	27
	28	29	30	31	..	..	..

THE DELTA METAL CO., LTD., 110, CANNON ST., LONDON, E.C.

POCKET-BOOK

OF

USEFUL FORMULÆ & MEMORANDA

FOR

Civil and Mechanical Engineers.

BY

SIR GUILFORD L. MOLESWORTH,

KNIGHT COMMANDER OF THE ORDER OF THE INDIAN EMPIRE;
FELLOW OF THE UNIVERSITY OF CALCUTTA,
MEMBER OF THE INSTITUTION OF CIVIL ENGINEERS,
MEMBER OF THE INSTITUTION OF MECHANICAL ENGINEERS,
CONSULTING ENGINEER TO THE GOVERNMENT OF INDIA FOR STATE RAILWAYS.

TWENTY-SECOND EDITION.

Revised and Enlarged.

LONDON: E. & F. N. SPON, 125, STRAND.
NEW YORK: 12, CORTLANDT STREET.

MDCCCLXXXVIII.

PREFACE

TO

THE FIRST EDITION.

Few are gifted with a memory so retentive, as not to require the aid of written formulæ, in working out the numerous calculations constantly necessary in the profession of an Engineer. But I am not aware of any book providing formulæ, to which on all ordinary emergencies he may easily refer, and which concisely and comprehensively furnish data for the various and rapid calculations so constantly needful in his work.

To a certain extent these requirements are supplied by Adcock's, Weale's, and Templeton's pocket-books; but these manuals, however generally useful and admirable, are not sufficiently comprehensive and portable for the purposes aimed at in the present publication.

When younger members of the profession have asked me to recommend some concise and comprehensive manual for ordinary operations, I have felt myself unable to make a satisfactory selection.

I had myself experienced the want of such a manual, and the consequent necessity of labour and search into various sources of information; in which what I needed was frequently either mixed up with extraneous matter, arranged in unpractical form, or clothed in mathematical terms so abstruse as to render it almost valueless.

This experience has led me from year to year to compile and note down for my own use many formulæ and memoranda. These, after considerable additions and careful revision, I now publish as a pocket manual, with the hope that other engineers may find it as useful to them as it has been to me.

Complex and difficult formulæ have as far as possible been avoided, and, in many cases, to the formulæ have been added an easy approximate rule. Throughout the book there is scarcely a formula which cannot be mastered by any one possessing little more than a mere knowledge of arithmetic. To facilitate the calculations of hydraulic formulæ, the crushing strains on columns and other formulæ, I have calculated the 5th, 4th, 3·6th and 1·7th powers for those numbers which are most likely to be required; and, that the book may in itself be complete for use when no other reference is at hand, I have added short tables of Logarithms, Natural and Logarithmic Sines, &c., Square and Cube Roots, Areas and Circumferences of Circles, &c., which are quite sufficient for all ordinary calculations.

Many of the formulæ, though appearing in a new shape, are not original, but merely simplified by me, so as to give the same results as before with less labour and complication. Some are inserted unchanged. Others I have deduced from practical experience of their usefulness.

While in justice making a general acknowledgment to many authors who have been consulted, but whose names could not be conveniently enumerated, I cannot deny myself the satisfaction of recording my special obligations to my friend, Mr. Henry Warriner; not only for many kind and useful suggestions in the revision of this book for publication, but for much valuable and practical information, which I have derived from him in the course of my professional connection with him in past years.

GUILFORD L. MOLESWORTH.

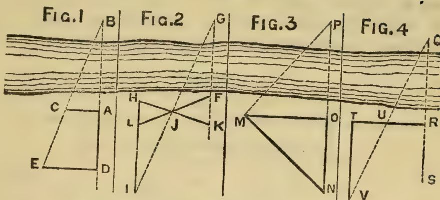
November, 1862.

MOLESWORTH'S

Pocket-book of Engineering Formulæ.

Chain Surveying.

INACCESSIBLE POINTS.



By Fig. 1. Measure off perpendiculars A C, D E, ranging the point C in line with E B; then

$$A\,B = \frac{A\,C \times A\,D}{D\,E - A\,C}.$$

By Fig. 2. Fix any line H K and bisect it in J. Make J L = J F, and range I in line with H L and with J G; then L I = F G.

By Fig. 3. Set off O M at right angles to O P and M N at right angles to M P; then

$$O\,P = \frac{O\,M^2}{O\,N}.$$

By Fig. 4. Set off R T at right angles to R Q and bisect R T in U. Set off T V at right angles to R T until V ranges in line with Q U; then T V = R Q.

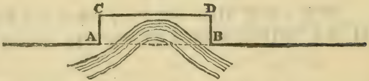
Chain Surveying—*continued.*

COMPUTATION OF ACREAGE.

Divide the area into convenient triangles, and multiply the base of each triangle in links by half the perpendicular in links; cut off 5 figures to the *right*, the remaining figures will be acres; multiply the 5 figures so cut off by 4, and again cut off 5 figures, and the remainder is in roods; multiply the 5 figures by 40, and again cut off for perches.

OBSTACLES IN RANGING SURVEY LINES.

Fig. 5.



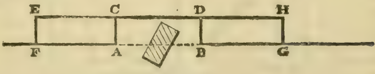


Fig. 6.

If it be possible to see over the obstacle but not to chain over it, lay off A C and B D (Fig. 5) equal to each other, and at right angles to the line, then A B = C D. If it be not possible either to chain or see over the obstacle, lay off the lines E F, A C, equal to each other, and at right angles to the line (Fig. 6); range the points D H in line with E C, and set off the lines D B, H G, equal to A C and E F, and at right angles to the line E H, then B and G are points for ranging the continuation of the line F A, and A B = C D.

TO SET OUT A RIGHT ANGLE WITH THE CHAIN.

Take 40 links on the chain, 30 links for the perpendicular and 50 for the hypothenuse.

For right-angled triangles, see Trigonometry.

USEFUL NUMBERS IN SURVEYING.

For Converting			Multiplier.	Converse.
Feet	into	links.	1·515	·66
Yards	,,	links.	4·545	·22
Square feet	,,	acres.	·0000229	43560
Square yards	,,	acres.	·0002066	4840
Feet	,,	miles.	·00019	5280
Yards	,,	miles.	·00057	1760
Chains	,,	miles.	·0125	80

For Table of links and feet, see "Links."

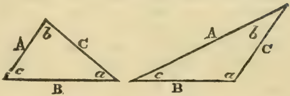
CHAINING ON SLOPES.

A = Angle of slope with horizon.
L = Length of line chained on the slope.
l = Length of line reduced to the horizontal.
l = L K. K = cos. A.

TABLE SHOWING VALUES OF K.

A.	K.	A.	K.	A.	K.	A.	K.	A.	K.	A.	K.
°		°		°		°		°		°	
5	·996	11	·982	17	·956	23	·92	29	·875	35	·819
6	·994	12	·978	18	·951	24	·913	30	·866	36	·809
7	·992	13	·974	19	·945	25	·906	31	·857	37	·799
8	·99	14	·97	20	·94	26	·899	32	·848	38	·788
9	·988	15	·966	21	·933	27	·891	33	·839	39	·777
10	·985	16	·961	22	·927	28	·883	34	·829	40	·766

Trigonometrical Surveying.



1.—Given the line B and the angles c and a, to find A. Find the angle $b = 180° - (c + a)$, then

$A = B \dfrac{\sin. a}{\sin. b}$;

$A = B \dfrac{\sin. (180° - a)}{\sin. b}$, if the angle a be greater than 90°.

2.—Given the lines A, B, and an opposite angle a, to find the angle b. $\text{Sin. } b = B \dfrac{\sin. a}{A}$.

3.—Given the lines B and C, and the included angle a, to find the side A;

$$A = \sqrt{B^2 + C^2 - 2\,B\,C \cos. a}.$$

Curvature and Refraction.

D = distance in statute miles.
C = curvature in feet = $\frac{2}{3}$ D^2 approximately.
C − R = curvature less refraction = $\frac{4}{7}$ D^2 approximately.

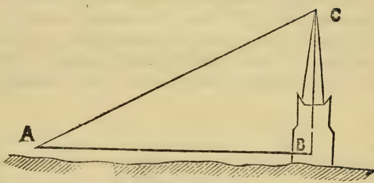
D.	C.	C − R.	D.	C.	C − R.	D.	C.	C − R.
1	·66	·57	6	24	20·57	12	96	82
2	2·67	2·29	7	32·67	28·00	14	130	112
3	6	5·14	8	42·67	36·57	16	170	146
4	10·67	9·14	9	54	46·30	18	216	185
5	16·67	14·29	10	66·67	57·14	20	266·7	228·6

To find the Distance in Feet when the Angle subtended by 1 Foot at that Distance is known.

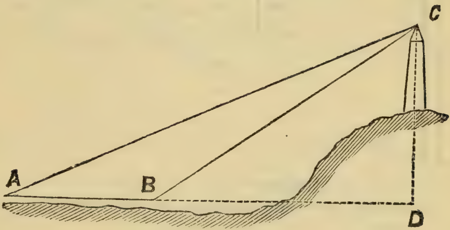
$$\text{Distance} = \frac{3437{\cdot}7}{A}.$$

A being the angle in minutes.

Measurement of Heights.

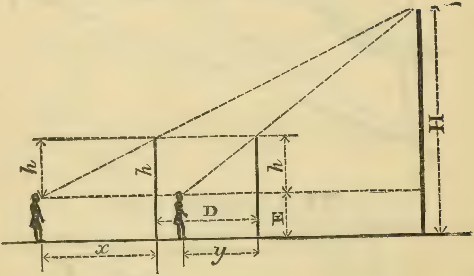


$$CB = \text{tan. } BAC \times AB.$$



$$CD = \frac{AB}{\text{cotan. } CAD - \text{cotan. } CBD}.$$

Approximate Measurement of Heights without an Instrument.



Measure any convenient length **D** on level ground; erect a staff first at one extremity, and ascertain the distance y from it at which the line of sight cuts the top of the staff and the object; then erect the staff at the other extremity of D, and ascertain the distance x in the same manner; deduct the height of the eye from the length of the staff to find h.

$$H = \frac{D\,h}{x - y} + h + E.$$

Measurement of Heights with Sextant.
(J. T. Hurst.)

Multiplier.	Angle.	Divisor.	Angle.
	° ′		° ′
1	45 0	1	45 0
2	63 26	2	26 34
3	71 34	3	18 26
4	75 58	4	14 2
5	78 41	5	11 19
6	80 32	6	9 28
8	82 52	8	7 8
10	84 17	10	5 43

Set the sextant to any angle in the Table, and the height will equal the distance multiplied or divided, as the case may be, by the number opposite to it.

Reduction of Base Lines to Level of Sea.
L = Length of base line measured in feet.
h = Height of base line above sea level in feet.
c = Correction in feet to be subtracted from the length of the base line.

$$c = \frac{L\,h}{20{,}890{,}000}$$

Plotting Angles without a Protractor.
On a given line prick off 100 with any convenient scale, and from the point so pricked off lay off at right angles with the same scale the natural tangent due to the angle (see Table of Natural Sines, &c.); or strike out a portion of a circle with radius 100 and lay off a chord = 2 sin. of half the angle required.

Dip of Horizon.

D = Dip of horizon in seconds.
H = Height of observer's eye in feet.
S = Distance of horizon in statute miles.
N = Do. do. nautical miles.

$D = 57{\cdot}4\sqrt{H}$. Approximate, varying with temperature.

$H = {\cdot}663\ N^2. \qquad = {\cdot}498\ S^2.$

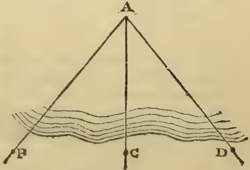
$S = 1{\cdot}42\sqrt{H}. \qquad N = 1{\cdot}23\sqrt{H}.$

Table of Dip and Distance of Horizon at Various Heights.

H.	S.	N.	Dip.	H.	S.	N.	Dip.
			′ ″				′ ″
5	3·16	2·75	2 8	80	12·67	11	8 33
10	4·48	3·89	3 1	90	13·44	11·66	9 4
15	5·49	4·76	3 42	100	14·14	12·3	9 34
20	6·34	5·5	4 16	150	17·35	15·06	11 43
25	7·10	6·15	4 47	200	20·04	17·4	13 32
30	7·76	6·73	5 14	300	24·54	21·3	16 34
35	8·38	7·27	5 39	400	28·34	24·6	19 8
40	8·98	7·78	6 3	500	31·62	27·5	21 23
45	9·51	8·25	6 25	1000	44·72	38·89	30 14
50	10·02	8·7	6 46	2000	63·37	55	42 47
60	10·97	9·52	7 24	3000	77·61	67·4	52 24
70	11·83	10·28	8 0	4000	89·68	77·8	60 33

Marine Surveying.

To determine the position of any sounding A when afloat take simultaneously the bearing of three known objects on shore, BCD, plot the angles on tracing paper, and move them on plan until the lines cut the points BCD.



Reduction of Soundings.

R = Total rise of tide in feet.
K = Correction to be subtracted from the sounding to reduce it to low water.
T = The time between high and low water.
t = The time of taking the sounding from *low* water.

$$K = \frac{R}{2}\left(1 + \cos. \frac{180\,t}{T}\right) \text{ when } \frac{180\,t}{T} \text{ exceeds } 90^\circ.$$

$$K = \frac{R}{2}\left(1 - \cos. \frac{180\,t}{T}\right) \text{ when it is less than } 90^\circ.$$

Tides.

The sea flows for about 6 hours from south to north in the northern hemisphere, so that entering the mouths of rivers it drives the river-waters back towards their source; after flowing for 6 hours the sea appears to rest for a quarter of an hour, after which it begins to ebb for 6 hours more, then there is another seeming pause for a quarter of an hour.

The sea ebbs and flows twice a day, falling gradually later by about 48 minutes, each period of flux and reflux being on an average about 12 hours and 24 minutes.

Tidal Phenomena.

The elevation towards the moon slightly exceeds the opposite one, and the intensity of the tidal wave diminishes from the equator towards the poles.

From the action of the sun every day, the sea is twice depressed and twice elevated, following the action of the moon, but in a less degree.

Spring tides are caused by the combined action of the sun and moon when both bodies are on the same side of the earth; neap tides by the action of one partly neutralizing that of the other, when they are in the quadratures subtending an angle of 90°.

The greatest elevations and depressions are not observed until the second or third day after full or new moon.

Tidal Phenomena—*continued.*

When the sun and moon are in conjunction and near the equinoxes the tides are greatest.

The action of the sun and moon are greater the nearer those bodies are to the earth.

Particular situations of shores, capes, straits, or rivers, disturb these general rules.

The mean force of the moon to cause tides is about $4\frac{1}{2}$ times that of the sun. Therefore, if the moon produce a tide of 9 feet, the sun will produce a tide of 2 feet; from which it follows that the spring tides will be 11 feet, and the neap tides 7 feet high. Tides are very irregular when passing over shoals into funnel-shaped channels; at Chepstow, in the Bristol Channel, the tide rises 50 feet, and in the Bay of Fundy 70 feet.

To allow tides their full motion, the ocean in which they are produced ought to be extended from east to west at least 90°.

Levelling with Thermometer.

B = Temperature of boiling water at any station (in degrees Fahr.) deducted from 212°.

H = Height of the station above the level of the sea in feet.

$$H = 520\,B + B^2.$$

This result is subject to the same correction for the temperature of the atmosphere as the reading of the barometer by multiplying the difference of height so found by K.

For values of K, see "Levelling with Barometer."

The values of K vary approximately in the proportion of ·0011 per degree Fahr.

TABLE OF FEET CORRESPONDING WITH THE BOILING POINT OF PURE WATER IN DEGREES AND DECIMALS OF A DEGREE FAHR.

Boiling point at the level of the sea being assumed at 212°. $T + t = 64°$.

Deg.	Decimals of a degree Fahr.										Diff.	Deg.
	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9		
°	feet.	feet.	feet.	feet.	feet.	feet.	feet.	feet.	feet.	feet.		°
211	521	469	417	365	313	260	208	156	104	52	5·21	211
210	1044	992	939	887	835	782	730	678	625	573	5·23	210
209	1569	1516	1464	1411	1359	1306	1254	1201	1149	1096	5·25	209
208	2096	2043	1991	1938	1885	1832	1780	1727	1674	1622	5·27	208
207	2625	2572	2519	2466	2413	2360	2308	2255	2202	2149	5·29	207
206	3156	3103	3050	2997	2944	2890	2837	2784	2731	2678	5·31	206
205	3689	3638	3582	3529	3476	3422	3369	3316	3263	3209	5·33	205
204	4224	4170	4117	4063	4010	3956	3903	3849	3796	3742	5·35	204
203	4761	4707	4654	4600	4546	4492	4439	4385	4331	4278	5·37	203
202	5300	5246	5192	5138	5084	5030	4977	4923	4869	4815	5·39	202
201	5841	5787	5733	5679	5625	5570	5516	5462	5408	5354	5·41	201
200	6384	6330	6275	6221	6167	6112	6058	6004	5950	5895	5·43	200
199	6929	6874	6820	6765	6711	6656	6602	6547	6493	6438	5·45	199
198	7476	7421	7367	7312	7257	7202	7148	7093	7038	6984	5·47	198
197	8025	7970	7915	7860	7805	7750	7696	7641	7586	7531	5·49	197
196	8576	8521	8466	8411	8356	8300	8245	8190	8135	8080	5·51	196
195	9129	9074	9018	8963	8908	8852	8797	8742	8687	8631	5·53	195
194	9684	9628	9573	9517	9462	9406	9351	9295	9240	9184	5·55	194
193	10241	10185	10130	10074	10018	9962	9907	9851	9795	9740	5·57	193
192	10800	10744	10688	10632	10576	10520	10465	10409	10353	10297	5·59	192

The correction for the temperature of the atmosphere must be made in the same manner as in Barometer readings, by multiplying by K.

LEVELLING WITH THE MOUNTAIN BAROMETER, CORRECTED OR ANEROID.

R = Reading of barometer at lower station in inches.
r = Reading of barometer at upper station.
T = Temperature of lower station in degrees Fahr.
t = Temperature of upper station.
K = Correction due to T + t. (For value of K, see Table below.)
H = Difference of upper and lower stations in feet.
H = 60000 (log. R − log. r) K approximately.

TABLE SHOWING VALUES OF K.

T+t.	K.	T+t.	K.	T+t.	K.	T+t.	K.	T+t.	K.
°		°		°		°		°	
40	·973	70	1·007	100	1·040	130	1·073	160	1·106
42	·976	72	1·009	102	1·042	132	1·076	162	1·108
44	·978	74	1·011	104	1·044	134	1·078	164	1·111
46	·980	76	1·013	106	1·047	136	1·080	166	1·113
48	·982	78	1·016	108	1·049	138	1·082	168	1·115
50	·984	80	1·018	110	1·051	140	1·084	170	1·117
52	·987	82	1·020	112	1·053	142	1·087	172	1·120
54	·989	84	1·022	114	1·056	144	1·089	174	1·122
56	·991	86	1·024	116	1·058	146	1·091	176	1·124
58	·993	88	1·027	118	1·060	148	1·093	178	1·126
60	·996	90	1·029	120	1·062	150	1·096	180	1·129
62	·998	92	1·031	122	1·064	152	1·098	182	1·131
64	1·000	94	1·033	124	1·067	154	1·100	184	1·133
66	1·002	96	1·036	126	1·069	156	1·102	186	1·135
68	1·004	98	1·038	128	1·071	158	1·104	188	1·137

Table of Feet corresponding to Different Readings of the Barometer.

Sea level assumed at 30 in. T + t = 64°.

Reading of Bar.	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9
29	886	796	706	617	528	439	351	263	175	87
28	1802	1709	1616	1524	1432	1340	1248	1157	1066	976
27	2753	2656	2560	2464	2368	2273	2178	2084	1990	1896
26	3739	3638	3539	3439	3340	3241	3143	3045	2947	2850
25	4763	4659	4554	4452	4349	4246	4144	4042	3940	3839
24	5830	5721	5613	5505	5398	5291	5185	5079	4973	4868
23	6942	6829	6716	6603	6491	6380	6269	6158	6048	5939
22	8103	7985	7867	7749	7632	7516	7400	7285	7170	7056
21	9319	9195	9071	8948	8826	8704	8583	8462	8342	8222
20	10593	10463	10333	10204	10076	9948	9821	9695	9569	9443
19	11933	11796	11660	11524	11389	11254	11121	10988	10856	10724
18	13346	13201	13057	12914	12771	12630	12489	12349	12210	12071
17	14839	14686	14533	14382	14231	14082	13933	13785	13638	13491
16	16423	16260	16098	15937	15778	15619	15461	15304	15148	14993
15	18109	17935	17763	17592	17421	17252	17084	16917	16751	16587
14	19911	19725	19541	19357	19175	18995	18815	18637	18460	18284
13	21847	21647	21449	21251	21056	20862	20669	20477	20287	20099

Deduct the tabular number due to the reading at the upper station from that of the lower station, and multiply the difference by K, see Table, the result will be the difference of the height of the two stations in feet.

Barometer.

Correction for Capillarity (to be *added*).

Diameter of tube (ins.)	·6	·55	·5	·45	·4	·55	·3	·25	·2	·1
Correction, unboiled (ins.)	·004	·005	·007	·01	·014	·02	·025	·04	·059	·087
Correction, boiled (ins.)	·002	·003	·004	·005	·007	·01	·014	·02	·029	·044

Correction for Latitude.

Positive from 0° to 45°; Negative from 45° to 90°.

Apparent Altitude.	Latitude. 0° 90°	10° 80°	20° 70°	30° 60°	40° 50°	45°
feet.	feet.	feet.	feet.	feet.	feet.	No correction for 45°.
1,000	2·6	2·5	2·0	1·3	·5	
2,000	5·3	5·0	4·1	2·6	·9	
3,000	7·9	7·5	6·1	4·0	1·4	
4,000	10·6	10·0	8·1	5·3	1·8	
5,000	13·2	12·4	10·1	6·6	2·3	
6,000	15·9	14·9	12·2	7·9	2·8	
7,000	18·5	17·4	14·2	9·3	3·2	
8,000	21·2	19·9	16·2	10·6	3·7	
9,000	23·8	22·4	18·3	11·9	4·1	
10,000	26·5	24·9	20·3	13·2	4·6	
11,000	29·1	27·4	22·3	14·6	5·1	
12,000	31·8	29·9	24·4	15·9	5·5	
13,000	34·4	32·4	26·4	17·2	6·0	
14,000	37·1	34·9	28·4	18·5	6·4	
15,000	39·7	37·3	30·4	19·9	6·9	
16,000	42·4	39·8	32·5	21·2	7·4	
17,000	45·0	42·3	34·5	22·5	7·8	
18,000	47·7	44·8	36·5	23·8	8·3	
19,000	50·3	47·3	38·6	25·2	8·7	
20,000	53·0	49·8	40·6	26·5	9·2	

Diurnal Barometric Wave.

The period of the wave varies according to the season from

January, maximum 9 P.M. and 10 A.M.
to June .. .. .. 11 P.M. „ 9 A.M.
January, minimum 3 P.M. „ 5 A.M.
to June .. .. .. 5 P.M. „ 3 A.M.

In the Tropics there is but little variation of period, the average being

Maximum, 10 P.M. and 9.30 A.M.
Minimum, 4 P.M. „ 3.30 A.M.

The intensity of the wave varies with the latitude.

At the level of the sea the average intensity in inches being at sea-level from ·09 to ·12 inch, and diminishing gradually to 0 about 65° or 70° north latitude.

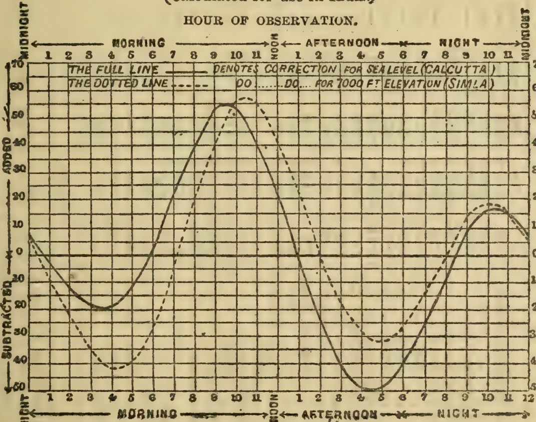
The intensity decreases with the elevation above the level of the sea.

DIAGRAM FOR CORRECTION OF BAROMETRICAL HEIGHT FOR DIURNAL WAVE.

(Calculated for use in India.)

HOUR OF OBSERVATION.

SCALE OF FEET TO BE SUBTRACTED FROM OR ADDED TO THE APPARENT ELEVATION AS CORRECTION FOR THE DIURNAL WAVE.



Note.—This diagram is intended for use when simultaneous observations cannot be obtained at both upper and lower stations, and a mean sea-level pressure and temperature has to be assumed for determining the elevation.

The correction can only be considered to be a rough approximation, as the diurnal wave is irregular in its movements.

Strength and Weight of Materials.

Metals.

	Specific Gravity.	Weight of a cubic foot.	Weight of a cubic inch.	Tensile Strength per sq. in.	Crushing Weight per sq. in.	Transverse Strength.
		lbs.	lbs.	tons.	tons.	tons.
Aluminium, sheet..	2·67	166·6	·096	—	—	—
„ „ cast ..	2·56	159·8	·092	—	—	—
Antimony, cast ..	6·72	419·5	·242	·47	—	—
Bismuth, cast.. ..	9·822	613·1	·353	1·45	—	—
Copper bolts	8·85	552·4	·318	17	—	—
„ cast	8·607	537·3	·31	8·4	—	—
„ sheet	8·78	548·1	·316	13·4	—	—
„ wire	8·9	555	·32	26	—	—
Gold	18·417	1150	·665	9·1	—	—
Iron, cast, from ..	7	437	·252	6	36	2
„ „ to	7·6	474·4	·273	13	64	3·4
„ „ average .	7·23	451	·26	7·3	48	2·6
„ wrought, from	7·6	474·4	·273	16	16	3
„ „ to	7·8	486·9	·281	29	18	5·5
„ „ average	7·78	485·6	·28	22	16·9	3·8
„ wire	—	—	—	40	—	—
Lead, cast	11·36	708·5	·408	·8	3·1	—
„ sheet	11·4	711·6	·41	1·5	—	—
Mercury	13·596	848·75	·49117	—	—	—
Platinum	21·531	1343·9	·775	—	—	—
„ sheet ..	23	1435·6	·828	—	—	—
Silver	10·474	653·8	·377	18·2	—	—
Steel	8	499	·288	52	150	—
„ plates	—	—	—	35	90	—
Tin, cast	7·291	455·1	·262	2·0	6·7	—
Zinc, cast	7	437	·252	3·3	—	—

Alloys.

Aluminium bronze, 90 to 95 per cent. copper	7·68	478·4	·276	32	58	—
Bell-metal (small bells)	8·05	502·52	·29	1·4	—	—
Brass, cast	8·4	524·37	·3	8	—	—
„ sheet	8·44	526·86	·301	14	—	—
„ wire	8·54	533·109	·307	22	—	—

Strength and Weight of Materials—*continued.*

Alloys—*continued.*

	Specific Gravity.	Weight of a cubic foot.	Weight of a cubic inch.	Tensile Strength per sq. in.	Crushing Weight per sq. in.	Transverse Strength.
		lbs.	lbs.	tons.		
Brass, 5 copper, 1 zinc	8·41	525·09	·3	13·7	—	—
" 4 " 1 "	8·448	527·36	·304	14·7	—	—
" 3 " 1 "	8·397	524·18	·3	13·1	—	—
" 2 " 1 "	8·299	518·06	·299	12·5	—	—
" 1 " 1 "	8·23	513·75	·296	9·2	—	—
" 1 " 2 "	8·283	517·06	·298	19·3	—	—
" 1 " 4 "	7·371	460·13	·265	1·9	—	—
Gold (standard) ..	17·724	1106·42	·638	—	—	—
Gun-metal, 10 copper, 1 tin	8·464	528·36	·306	16·1	—	—
Ditto, 9 copper, 1 tin	8·462	528·24	·305	15·2	—	—
Ditto, 8 " 1 "	8·459	528·05	·305	17·7	—	—
Ditto, 7 " 1 "	8·456	527·89	·305	13·6	—	—
Pewter	—	—	—	—	—	—
Silver (standard) ..	10·312	643·72	·371	—	—	—
Speculum metal ..	7·447	464·87	·264	3·1	—	—
White metal (Babbett)	7·31	456·32	·263	—	—	—

Timber.

	Specific Gravity.	Weight of a cubic foot.	Weight of a cubic inch.	Tensile Strength per sq. in.	Crushing Weight per sq. in.	Transverse Strength.
		lbs.	lbs.	lbs.	lbs.	lbs.
Acacia .. from	·71	44	·025	16,000	—	1867
" .. to	·79	49	·028	—	—	—
Ash	·69	43	·025	12,000	8,600	2000
"	·76	47	·027	17,000	9,300	3000
Beech .. from	·69	43	·025	11,000	7,700	1500
" .. .. to	·696	43	·025	22,000	9,300	2000
Birch	·711	44	·026	15,000	3,300	1900
"	·730	45	·026	—	6,000	1930
Box	1·28	80	·046	20,000	10,300	2445
Cedar, West Indian	·748	47	·026	5,000	5,700	1443
" American ..	·554	35	·020	—	—	766
" Lebanon ..	·486	30	·017	11,000	5,800	1300
Chestnut..	·606	38	·022	12,000	—	1770
Cork..	·240	15	·008	—	—	—
Deal, Christiana ..	·689	43	·025	12,000	5,850	1562
Ebony	1·187	74	·043	—	19,000	2100

STRENGTH AND WEIGHT OF MATERIALS—*continued.*

TIMBER—*continued.*

	Specific Gravity.	Weight of a cubic foot.	Weight of a cubic inch.	Tensile Strength per sq. in.	Crushing Strain per sq. in.	Transverse Strength.
		lbs.	lbs.	lbs.	lbs.	lbs.
Elm, English	·553	34	·02	13,200	10,300	782
„ „	·579	36	·021	14,000	—	1100
„ Canadian ..	·725	45	·026	—	—	1920
Fir, spruce	·512	32	·018	10,100	6,500	1490
Hornbeam	·76	47	·027	20,000	4,600	—
Ironwood	1·15	71	·041	—	—	3000
Jackwood	·67	42	·024	—	—	1830
Larch	·543	34	·019	8,900	3,200	1330
„	·556	35	·02	10,200	5,500	1660
Lignum vitæ	1·333	83	·048	11,800	10,000	3440
Lime	·564	35	·02	—	—	—
Mahogany, Nassau	·668	42	·024	—	—	1719
„ Honduras	·560	35	·02	21,000	8,000	1910
„ Spanish	·852	53	·031	—	8,200	1300
Maple	·675	42	·025	10,600	—	1694
Oak, African	·988	62	·035	—	—	2523
„ American, red	·85	53	·03	10,000	6,000	1680
„ „ white	·779	49	·028	—	—	—
„ English	·777	48	·028	10,000	6,400	1600
„ „	·934	58	·034	19,000	10,000	1690
Pine, red	·576	36	·021	12,000	5,400	1200
„ „	·657	41	·024	14,000	7,500	1530
„ white	·432	27	·015	—	—	1229
„ „	·553	34	·02	—	—	—
„ yellow	·508	32	·018	—	5,300	1185
„ Dantzic	·649	40	·023	8,000	5,400	1426
„ Memel	·550	34	·02	—	—	1348
„ „	·601	37	·021	—	—	—
„ Riga	·466	29	·017	—	—	—
„ „	·654	41	·023	14,000	—	1383
Satinwood	·96	60	·034	—	—	3200
Teak	·74	46	·026	8,000	12,000	2110
„	·86	54	·031	15,000	—	—

Note.—The transverse strength is the coefficient K in the formula for strength of rectangular beams, but in lbs. The modulus of rupture may be found by multiplying the transverse strength by 6.

Strength and Weight of Materials—*continued.*

Stones, &c.

	Specific Gravity.	Weight of a cubic foot.	Weight of a cubic inch.	Tensile Strength per sq. in.	Crushing Strain per sq. in.	Transverse Strength.
		lbs.	lbs.	lbs.	lbs.	lbs.
Basalt, Scotch	2·95	184	·106	1,469	8,300	—
„ Greenstone	2·9	181	·104	—	17,200	—
„ Welsh	2·75	172	·099	—	16,800	—
Chalk	2·33	145	·084	—	501	—
„	2·62	162	·094	—	—	—
Firestone	1·8	112	·065	—	—	—
Granite, Aberdeen grey ..	2·62	163	·094	—	10,900	—
„ „ red ..	2·62	165	·095	—	—	—
„ Cornish	2·66	166	·096	—	14,000	—
„ Mount Sorrel ..	2·67	167	·096	—	12,800	—
Limestone, Compact ..	2·58	161	·093	—	7,700	—
„ Purbeck	2·6	162	·093	—	9,160	—
„ Anglesea ..	—	—	—	—	7,579	—
„ Blue Lias ..	2·467	154	·089	—	—	—
„ Lithographic ..	2·6	162	·093	—	—	—
Marble, Statuary	2·718	170	·098	722	3,216	—
„ Italian	2·726	170	·098	—	9,681	—
„ Brabant block ..	2·697	168	·097	—	9,219	—
„ Devonshire	—	—	—	—	7,428	—
Oolite, Portland stone ..	2·423	151	·087	—	4,100	—
„ Bath stone	1·978	123	·072	—	—	—
Sandstone, Arbroath pavement	2·477	155	·089	1,261	7,884	—
„ Bramley-Fall ..	2·5	156	·09	—	6,050	—
„ Caithness	2·638	165	·095	1,054	6,490	857
„ Craglieth	2·45	153	·088	453	5,287	—
„ Derby grit ..	2·4	150	·086	—	3,100	—
„ Red (Cheshire)	2·15	133	·077	—	2,185	—
„ Yorkshire paving	2·51	157	·09	—	5,714	—
Slate, Anglesea	2·87	179	·103	9,600	10,000	
„ Cornwall	2·51	157	·09	to	to	
„ Welsh	2·88	180	·104	12,800	21,000	1961
Trap	2·72	170	·098	—	—	—

Strength and Weight of Materials—*continued*

Miscellaneous Substances.

	Specific Gravity.	Weight of a cubic foot.	Weight of a cubic inch.	Tensile Strength per sq. in.	Crushing Strain per sq. in.
		lbs.	lbs.	lbs.	lbs.
Asphalte	2·5	156	·09	—	—
Brick, common from	1·6	100	·057	—	—
„ „ .. to	2	125	·072	—	—
„ London stock ..	1·84	115	·066	—	—
„ red	2·16	134	·077	—	808
„ Welsh fire ..	2·4	150	·086	—	—
„ Stourbridge fire	2·2	137	·079	—	1717
Cement, Portland, in powder } from	3·1	86	·05	400	3795
„ „ to	3·155	94	·054	600	5984
„ Roman	1·6	100	·057	185	—
Clay	1·9	119	·068	—	—
Coal, anthracite	1·53	95	·055	—	—
„ cannel	1·272	79	·046	—	—
„ Glasgow	1·29	80	·046	—	—
„ Newcastle	1·269	79	·045	—	—
Coke	·744	46	·026	—	—
Concrete, ordinary ..	1·9	119	·068	—	—
„ in cement ..	2·2	137	·079	—	—
Earth .. .. from	1·52	77	·054	—	—
„ .. .. .. to	2·00	125	·072	—	—
Glass, flint	3·078	192	·111	2413	27,500
„ crown	2·52	157	·091	2546	31,000
„ common green..	2·528	158	·091	2896	31,876
„ plate	2·76	172	·099	—	—
Gutta-percha	·966	60	·035	—	—
Gypsum	2·286	143	·082	71	—
India-rubber	·93	58	·033	—	—
Ivory	1·82	114	·065	—	—
Lime, quick..	·843	53	·03	—	—
Mortar .. .. from ..	1·38	86	·049	—	—
„ .. .. to ..	1·9	119	·068	—	—
„ .. .. average	1·7	106	·061	—	—
Pitch	1·15	69	·041	—	—
Plumbago	2·267	140	·082	—	—
Sand, quartz	2·75	171	·099	—	—
„ river	1·88	117	·067	—	—

STRENGTH AND WEIGHT OF MATERIALS—*continued.*

MISCELLANEOUS SUBSTANCES—*continued.*

	Specific Gravity.	Weight of a cubic foot.	Weight of a cubic inch.
		lbs.	lbs.
Sand, pit (coarse)	1·61	100	·058
" " (fine)	1·52	95	·054
" (Thames)	1·64	102	·059
Shingle	1·42	88	·051
Tallow	·94	59	·034
Tar	1·016	63	·036
Tile, common .. from	1·81	112	·065
" " .. .. to	1·85	115	·066

LIQUIDS, &c.

	Specific Gravity.	Weight of a cubic foot.	Weight of a cubic inch.
		lbs.	lbs.
Water distilled 39°	1	62·425	·036
" sea	1·027	64	·037
Acetic acid	1·06	66	·038
Alcohol, absolute..	·792	49	·028
" proof	·916	57	·033
Æther	·716	45	·026
Hydrochloric acid	1·2	75	·043
Nitric acid	1·217	75	·044
Oil, linseed	·94	58	·034
" olive	·915	57	·033
" whale	·923	58	·033
Sulphuric acid	1·84	115	·066

GASES, &c.

Air	·001293	·08072	·00004655
Carbonic acid	·00197	·123	·000071
Hydrogen	·0000895	·0056	·0000032
Nitrogen	·00125	·078	·000045
Olefiant gas	·00127	·079	·000046
Oxygen	·00143	·089	·000051
Steam	·00088	·055	·0000317

Modulus of Elasticity.

The modulus of elasticity of any material is the force that would lengthen a bar of that material of 1 inch section to double its length, or would compress it till its length became zero; supposing it possible to stretch or compress the bar to this extreme extent without breaking it, and that the following relation between stress and strain held good :—

a = Alteration in length due to any force F less than the modulus.
A = Alteration due to the modulus E.

$$\frac{a}{A} = \frac{F}{E}.$$

To find the Compression or Extension of any Body under a given Strain within its Limits of Elasticity. W.

(See next page).

L = Length in feet of body strained.
l = Increase or decrease of length in feet caused by a strain f.
f = Force of the strain in lbs. per square inch.
E = Modulus of elasticity (for values of E see next page).

$$l = \frac{Lf}{E}; \qquad E = \frac{Lf}{l}; \qquad f = \frac{lE}{L}.$$

Determination of E from the Deflection of a Beam Freely Supported at Ends and Loaded at Centre.

l = Clear distance between supports in inches.
b = Breadth of beam in inches.
d = Depth of beam in inches.
W = Weight in lbs.
x = Deflection in inches produced by W.

$$E = \frac{W l^3}{4 b d^3 x}.$$

MODULUS OF ELASTICITY.

E = Modulus of elasticity; 1 inch being the unit of area.
M = Length corresponding with modulus.
W = Weight each square inch will bear without permanent alteration in length.

	M.	E.	W.
	feet.	lbs.	lbs.
METALS—			
Brass	2,460,000	8,930,000	6,700
Gun-metal	2,790,000	9,873,000	10,000
Iron, cast	5,750,000	18,400,000	15,300
Iron, wrought ..	7,550,000	24,920,000	17,800
Lead	146,000	720,000	1,500
Steel .. from	8,530,000	29,000,000	45,000
" .. .. to	12,354,000	42,000,000	65,000
Tin	1,453,000	4,608,000	2,880
Zinc	4,480,000	13,680,000	5,700
STONES, &c.—			
Marble	2,150,000	2,520,000	4,900
Slate	13,240,000	15,800,000	—
Portland	1,672,000	1,533,000	1,500
TIMBER—			
Ash	4,970,000	1,640,000	3,796
Beech	4,600,000	1,345,000	3,113
Elm	5,680,000	1,340,000	3,102
Fir, red	8,330,000	2,016,000	4,667
Larch	4,415,000	1,074,000	2,486
Mahogany	6,570,000	1,596,000	3,694
Oak	4,730,000	1,700,000	3,935

TENACITY OF WROUGHT IRON AND STEEL.

	Breaking Weights in Tons per Square Inch of			
	Original Section.		Fractured Section.	
	Highest Class.	Lowest Class.	Highest Class.	Lowest Class.
Steel bars for tools	59·3	45	62·1	59·1
" " rivets and bolts	47·9	41·1	70·9	62·2
" " puddled steel	31·9	28	49·7	31·8
Steel plates	44·3	32·3	51	35·7
Iron bars, Yorkshire	29·6	27	58·8	51
" " Staffordshire ..	28	24·7	65·4	33·6
" " Lanarkshire.. ..	28·9	20·8	52·6	21·4
" " Lancashire	27	24	46·6	38·5
" " Swedish	21·5	21·3	66·8	54
" " Russian..	25·3	22·1	34·7	32·2
" " Scrap	24·7	17·2	42	18·8
" " South Wales ..	17·2	13·2	17·6	13·3
Iron plate, Yorkshire	25·3	22	34	24·8
" " Staffordshire ..	24·1	20·3	27·4	22·3
" " Lanarkshire ..	22·9	18·6	27	19
Iron straps and angle-irons for strap building	25	18·5	30	20·5
Angle-iron, Lanarkshire ..	25	23·1	32	28
" " Staffordshire ..	25	22·3	31·9	26

This Table has been compiled from the valuable experiments of Mr. Kirkaldy, which have thrown much light on the rules which govern the fracture of iron. Amongst other points the experiments have shown conclusively—

1st. That the breaking strain of iron and steel does not (as hitherto assumed) indicate the quality—a high breaking strain *may* be due to hard unyielding character, or a low one may be due to

extreme softness. The contraction of *area at the fracture* forms an essential element in estimating the quality.

2nd. The breaking strain of iron and puddled steel plates is greater in the direction in which they have been rolled than in the direction of their breadth; but in cast steel the reverse.

3rd. Iron when fractured suddenly produces a crystalline fracture; but if gradually, a fibrous fracture. This accounts for the anomaly in the supposed change of iron from a fibrous to a crystalline character. Sudden shoulders which prevent a regular elongation of fibre cause a sudden snap.

4th. Strength of steel is reduced by being hardened in water; but both its hardness and toughness are increased by being hardened in oil. Iron heated, and suddenly cooled in water, is hardened, and the breaking strain (if gradually applied) is increased, but it is more likely to snap suddenly. It is softened and its breaking strain reduced if heated and allowed to cool gradually. Iron if brought to a white heat is injured if it be not at the same time hammered or rolled. Case-hardening bolts weakens them.

5th. The shearing strain of steel rivets is one-fourth less than their tensile strength. The ordinary proportions of iron rivets are too small when *steel* rivets are used for *steel* plates.

6th. The specific gravity is found to indicate the quality pretty correctly.

7th. The experiments on iron give the following breaking strains;—

	Highest. Tons per sq. inch.	Lowest. Tons per sq. inch.	Mean. Tons per sq. inch.
Rolled bars ..	30·7	19·9	25·7
Angle-irons ..	28·4	17	24·4
Plates lengthways	28	16·7	22·6
" crossways	27	14·5	20·6

Notes on Strength of Materials.

Wet timber is not so strong as dry; in some cases it is not half the strength of dry.

Crushing weight of a sphere = ·26 circumscribed cube.
" " roller = ·32 " square.

Cold-blast iron is stronger than hot-blast.

Annealing cast iron diminishes its tensile strength.

Remelting (up to ten or twelve meltings) or prolonged fusion increases the strength and density of cast iron. Softer irons will best bear remelting.

Indirect strains reduce the tensile strength of cast iron.

Additional strength should be given to cast-iron girders that take the load on one side of the bottom flange.

The tenacity of cast iron is only one-third that of wrought iron, and should not be subjected to more than one-sixth of the breaking strain.

Tensile strain on wrought iron should not exceed one-fourth of the breaking weight.

Annealing iron wire diminishes its strength.

High temperature in casting is injurious to gun-metal.

Plated webs are more economical than braced webs in shallow girders or near the ends of long girders. In small lattice girders it is better to make the lattices uniform throughout.

Strength of Iron.

Name.	Description.	Specific Gravity.	Breaking Weight. Tensile.	Transverse.	Torsion.	Crushing.
Stockton-on-Tees ..	No. 3 pig	7·135	22271	6932	6305	87063
Hematite Co.	No. 2 pig	7·214	17958	5538	5299	82265
Weardale Co.	No. 3 pig	7·158	21859	7374	6369	93989
Butterley Co.	No. 3 pig	7·126	23265	6692	6940	91661
Lord Ward's	Cold-blast pig ..	7·052	25872	6992	6833	94077
Blaen Avon	Cold blast No. 1	7·137	25456	8873	5966	95775
Dr. Price's ..	Improved (P) ..	7·259	28960	9120	—	—
Mean of 51 samples	..	7·140	23257	7102	6056	91061

The breaking weights above are reduced to lbs. per square inch. The transverse breaking weight represents the strain necessary to break a bar 1 inch square projecting horizontally 1 inch beyond the point of support, the weight being applied at the outer end.—*Ordnance Experiments.*

Shearing of Oak Treenails (*Dockyard Experiments*).

Diameter of treenails, inches..	1	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$
Shearing force, tons	1·6	2·3	2·95	3·9
Tons per square inch of section	2·03	1·88	1·67	1·62

ADMIRALTY TESTS FOR STEEL.

TENSILE AND EXTENSION TESTS.

1. Strips cut lengthwise or crosswise of the plate to have an ultimate tensile strength of not less than 26, and not exceeding 30 tons per square inch of section, with an elongation of 20 per cent. in a length of 8 inches.

TEMPERING TEST.

2. Strips cut lengthwise of the plate, 1½ inch wide, heated uniformly to a low cherry-red, and cooled in water of 82° Fahrenheit, must stand bending in a press to a curve of which the inner radius is one and a half times the thickness of the plates tested.

3. The strips are to be cut in a planing machine, and are to have the sharp edges taken off.

4. The ductility of every plate is to be ascertained by the application of one or both of these tests to the shearing, or by bending them cold by the hammer on the Contractor's premises, and at his expense.

5. All plates to be free from lamination and injurious surface defects.

6. One plate to be taken for testing by tensile, extension and tempering tests from every invoice, provided the number of plates does not exceed 50. If above that number, one for every addition of 50, or portion of 50. Plates may be received or rejected without a trial of every thickness on the invoice.

7. The pieces of plate cut out for testings are to be of parallel width from end to end, or for at least 8 inches of length.

When the plates are ordered by thickness, their weight is to be estimated at the rate of 40 lbs. per square foot for plates of 1 inch thick, and in proportion for plates of all other thicknesses: the weight so produced is not to be exceeded, but a latitude of 5 per cent. below this will be

Admiralty Tests for Steel—*continued.*

allowed for rolling in plates of half an inch in thickness and upwards, and 10 per cent. in thinner plates.

These weights may be ascertained by weighing as much as 10 tons at a time.

TESTS FOR ANGLE, BULB, OR BAR STEEL.

The whole of the steel to stand a tensile strain of 26 tons to the square inch, and not to exceed 30 tons to the square inch.

Also to stand the extension and tempering tests described for plates.

All the cross ends to be cut off. One bar is to be taken for testing from every invoice, providing the number of bars does not exceed 50; if above that number, one for every additional 50, or portion of 50.

Lloyd's Tests for Steel used in Ship-building.

Strips cut lengthwise or crosswise of the plate, and also angle and bulb steel, to have an ultimate tensile strength of not less than 27, and not exceeding 31 tons per square inch of section, with an elongation corresponding to 20 per cent. on a length of 8 inches before fracture.

Strips cut from the plate, angle or bulb steel to be heated to a low cherry-red, and cooled in water of 82° Fahrenheit, must stand bending double round a curve of which the diameter is not more than three times the thickness of the plates tested.

No reduction will be allowed in the sizes of rivets from those which would be required by the Rules for the vessels if built of iron.

In other respects the Rules for the construction of iron ships will apply equally to ships built of steel.

Strength of various Materials. (Barlow.)

Material.	Ultimate Strength. Tons per sq. inch.			Working Strain. Tons per sq. inch.		
	Tension.	Compression.	Shearing.	Tension.	Compression.	Shearing.
Steel bars	45	70	30	9	9	5
Steel plates	40	—	—	8	—	—
Wrought-iron bars	25	17	20	5	$3\frac{1}{2}$	4
" plates	$22\frac{1}{2}$	17	20	$4\frac{1}{2}$	$3\frac{1}{2}$	4
Iron wire cables ..	40	—	—	8	—	—
Cast iron	$7\frac{1}{2}$	48	14	$1\frac{1}{2}$	9	3
Ash	$7\frac{1}{2}$	4	$\frac{3}{4}$	$1\frac{1}{4}$	$\frac{2}{3}$	$\frac{1}{8}$
Beech	5	4	—	1	$\frac{2}{3}$	—
Elm	6	$4\frac{1}{2}$	$\frac{3}{4}$	1	$\frac{2}{3}$	$\frac{1}{8}$
Fir	5	$2\frac{1}{2}$	$\frac{1}{2}$	1	$\frac{1}{2}$	$\frac{1}{12}$
Oak	$6\frac{1}{2}$	$3\frac{1}{2}$	1	1	$\frac{1}{2}$	$\frac{1}{6}$
Teak	$6\frac{1}{2}$	5	—	1	1	—
Granite	—	$3\frac{1}{2}$	—	—	$\frac{1}{2}$	—
Sandstone	—	$1\frac{1}{2}$	—	—	$\frac{1}{4}$	—
Brick in cement ..	$\frac{1}{7}$	$\frac{1}{4}$ to $\frac{7}{10}$	—	50 lbs.	180 lbs.	—

Lloyd's Rules for Iron used in the Construction of Iron Masts, Yards, &c.

The iron should be of a good malleable quality, and quite free from surface or other defects.

The iron should stand a tensile strain of 20 tons to the square inch, and should be capable of standing the following bending tests when cold without fracture, through the angles undermentioned.

Thickness of plate	$\frac{9}{16}$	$\frac{8}{16}$	$\frac{7}{16}$	$\frac{6}{16}$	$\frac{5}{16}$	$\frac{4}{16}$	$\frac{3}{16}$
With the grain ..	25°	30°	37°	47°	55°	65°	70°
Across the grain	8°	11°	13°	15°	17°	20°	25°

The plates to be bent over a slab, the corner of which should be rounded with $\frac{1}{4}$ inch radius.

Tests of Iron. (Indian Store Department.)

Material.	Ultimate Stress. Tons per sq. in.		Contraction per cent. of area at fracture.	
	Highest Class.	Lowest Class.	Highest Class.	Lowest Class.
Bars, round & square.	27	23	45	20
Do. flat	26	22	40	16
Angle or T	25	21	30	12
Plate lengthways ..	24	20	20	8
Do. crossways ..	22	17	12	3

Materials tested to 4 per cent. of total value.

Materials under specified strain are accepted if the contraction is proportionally higher.

Admiralty Tests for Iron Plate.

Hot, to bend without fracture from 90° to 125°.

Cold Test, to bend without fracture to the following angles:—

	Lengthways.	Crossways.
1 in. plate	10° to 15°	5°
¾ ,, ...	20° ,, 25°	5° to 10°
½ ,, ...	30° ,, 35°	10° ,, 15°
¼ ,, ...	55° ,, 70°	20° ,, 30°

Tests for Cast Iron.

A common test for cast iron is 1 ton on the centre of an inch square bar 1 foot between supports; or 30 cwt. on the centre of a bar 2 inches deep × 1 inch wide and 3 feet between supports—the bar to bear the load without breaking.

Turner's Scale for Steel.

I.	contains from	1·65 to 1·40	carbon.
II.	,,	1·40 ,, 1·15	,,
III.	,,	1·15 ,, 0·90	,,
IV.	,,	·90 ,, ·65	,,
V.	,,	·65 ,, ·40	,,
VI.	,,	·40 ,, ·15	,,
VII.	,,	·15 ,, ·0	,,

Experiments on Steel for Ship-building.

(Naval Architects, 1878. B. Martell.)

1. Iron plates with butt straps and double chain riveting, holes punched, linear tensile strain 17·9 tons, broke through rivet holes.

2. Steel plates not annealed after punching, 16·7 tons per square inch, rivets sheered.

3. Same as 2, but with zigzag riveting, 19·2 tons.

4. Steel plates, same as 3, with steel rivets, 22·5 tons per square inch; rivets shearing in some cases, plates breaking in others.

5. Steel plates very thin suffer less from punching than iron.

6 Difference in loss of strength by punching steel and iron does not require special precautions up to $\frac{1}{2}$ inch thick.

7. Above $\frac{1}{2}$ inch thick the loss to iron varied from 20 to 23 per cent., and in steel from 22 to 33 per cent.

8. By annealing after punching the whole of the lost strength was restored, and in some cases greater relative strength was obtained than existed in the original plate. (Dr. Siemens is of opinion that nothing is gained by annealing.)

9. The steel was only injured a small distance round the punched holes, and by riming from $\frac{1}{16}$ to $\frac{1}{8}$ round the holes the injured part was removed, and no loss of strength was observed any more than if the hole had been drilled. In drilled plates no appreciable loss of tensile strength was observed:—

Boiler plate .. .. 7·618 specific gravity.
Mild steel .. .. 7·820 „ „

Proportional Strength of "Ship" and "Bridge" Steel. (Adamson.)

	Tensile Strain. Tons per sq. in.	Permanent Set. Tons per sq. in.	Carbon.	Manganese.	Silicon.	Sulphur.	Phosphorus.
Mild Ship Steel	27 to 30½	18¾ to 22½	·09	·454	Trace	·049	·033
Bridge Steel ..	57 to 65½	35½ to 46¾	·420	1·22	·074	·025	·048

CORROSION OF IRON AND STEEL. (B. H. Thwaite.)

C = Coefficient of corrosion during 1 year's exposure in lbs. avoirdupois per square foot. (For value of C, see Table.)

W = Weight in lbs. of 1 foot length of the section exposed.

L = Length in feet of the perimeter exposed. If both the inside and outside perimeters are exposed to the corrosive action, they must both be included.

* Y = The number of years' life of the metal $= \dfrac{W}{C\,L}$.

TABLE OF VALUES OF C.

	Corroding Agents.					
	Foul sea-water.	Clear sea-water.	Foul river-water.	Pure air or clear river-water.	Air of city or manufacturing district or sea air.	Sea-water of average foulness.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Cast iron	·0656	·0635	·0381	·0113	·0476	—
Wrought iron	·1956	·1285	·1440	·0123	·1254	—
Steel	·1944	·0970	·1133	·0125	·1252	—
Cast iron (skin removed by planing)	·2301	·0888	·0728	·0109	·0884	—
Cast-iron surface protected by galvanizing	·0895	·0359	·0371	·0048	·0199	—
Cast iron in contact with brass						·1908
„ „ copper						·2003
„ „ gun-metal						·3493
Best wrought iron in contact with brass						·2779
„ „ „ copper						·4012
„ „ „ gun-metal						·4537

If painted once a year, multiply the result by 2·0.
„ „ in 2 years, „ „ 1·8.
„ „ „ 3 „ „ „ 1·6.

* Y is based on the assumption that the metal is tolerably uniform in thickness, otherwise the thin portions will have a shorter life than the average of the section.

In experiments of iron in acid, it was found that the metals, according to their impurities, lost most in the same time—steel less than iron, soft steel less than hard steel. On the second day the soft steel lost more than hard; on the fourth day the loss was equal.

NOTES ON IRON.

CLASSIFICATION OF PIG IRON.

No. 1 (IRON). Fracture dark grey, with high metallic lustre. Crystals large, with lustre like newly cut lead; is useful for fine castings, being easily fused and fluid when melted.

No. 2 is intermediate between No. 1 and No. 3.

No. 3. Fracture of a lighter grey than No. 1, with less lustre; crystals larger and brighter at the centre than at the sides, useful for large castings.

No. 4 (or BRIGHT). Fracture light grey, with small crystals and little lustre; is not sufficiently fusible for casting, and is generally used in the manufacture of wrought iron.

No. 5 (MOTTLED). Fracture dull white, with pale greyish specks and a line of white iron round the edge of the fracture.

No. 6 (WHITE). Fracture white, with little lustre; granulated, but with radiating crystalline appearance. It is the worst, hardest, and most brittle of the pig irons, and is only used for the manufacture of inferior bar iron.

PERCENTAGE OF CARBON IN IRON AND STEEL.

Spiegeleisen	4·3 to 6·9	Masons' Tool steel	0·6
Swedish Pig	4·8	Railway Tire	·27 to ·32
Grey Pig	2·8 to 3·5	Steel Rails	·24 to ·30
Mottled and White	2·10 to 3·0	Hard Bar Iron	·4
Refined Iron	3·0	Ditto, Swedish	·3
Puddled Steel, hard	1·38	Staffordshire Plate	·1[illegible]
Ditto, soft	·5	Armour Plate	·17
Cast Steel	1·34	Swedish Bar, soft	·07
File Steel	1·2	Low Moor	·016
Double Shear Steel	·7		

Notes on Iron—*continued.*

FOREIGN SUBSTANCES IN IRON AND STEEL.

Silicon is generally excluded as slag, its presence makes iron hard and brittle; but up to ·08 per cent. it will do no harm, provided ·3 of Manganese is present with it.

Sulphur makes iron and steel "red-short."

Phosphorus. 0·5 to 0·8 per cent. is sufficient to produce cold-shortness in iron; in steel, phosphorus to an extent of 0·2 per cent. does not affect the working or hammering of steel; but rails with more than ·08 per cent. will not stand the required tests.

Manganese. 0·5 per cent. is sufficient to make iron cold-short; it is valuable in iron to be converted into steel.

Arsenic produces red-shortness in iron, but is valuable in chilling; it increases the hardness of steel at the expense of toughness.

Copper renders steel red-short.

Tungsten renders steel hard and tenacious.

Vanadium improves the ductility of iron for wire-drawing.

Carbon. ·25 per cent. gives malleable iron; ·50 per cent. gives steel; 1·75 gives the limit of welding steel; 2·00 gives the lowest limit of cast iron.

MALLEABLE CASTINGS.

Malleable castings are formed by subjecting the castings to a process of annealing in boxes with hematite iron ore or black oxide of iron. The boxes are kept in an annealing oven under equable heat, the duration of the process depending on the form and size of the castings.

Weight of Metals.

WROUGHT IRON.

Cubic inches × ·28 = lbs. avoirdupois.
" ÷ 100 = qrs.
" ÷ 400 = cwt.

Thickness of plates	in inches	× 40	=	lbs. per sq. ft.
" "	eighths	× 5	=	" "
" "	tenths	× 4	=	" "
Sectional area	in inches	× 3·34	=	lbs. per lin. ft.
" "	eighths	× ·052	=	" "
" "	inches	× 10	=	lbs. per lin. yd.

Lbs. per lineal yard × ·7857 = tons per mile run.

Diameter of round iron in inches squared × 2·64 = lbs. per foot run.

VARIOUS METALS.

Multipliers to convert the weights as found above into the weights of other metals.

Weight of wrought iron	× ·92	=	weight of	zinc.
" " "	× ·93	=	"	cast iron.
" " "	× ·94	=	"	tin.
" " "	× 1·02	=	"	steel.
" " "	× 1·09	=	"	brass.
" " "	× 1·15	=	"	copper.
" " "	× 1·47	=	"	lead.
Cube inches "	× ·252	=	lbs. of	zinc.
" " "	× ·26	=	"	cast iron.
" " "	× ·262	=	"	tin.
" " "	× ·288	=	"	steel.
" " "	× ·3	=	"	brass.
" " "	× ·32	=	"	copper.
" " "	× ·41	=	"	lead.

A bar of wrought iron 1 × 1 and 1 yard long weighs 10 lbs.

Weight of a Lineal Foot of Flat Bar Iron in lbs.

Breadth in inches.	Thickness in Fractions of inches.								
	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1
1	·83	1·04	1·25	1·46	1·67	2·08	2·50	2·92	3·34
$1\frac{1}{8}$	·93	1·17	1·40	1·64	1·87	2·34	2·81	3·28	3·75
$1\frac{1}{4}$	1·04	1·30	1·56	1·82	2·08	2·60	3·13	3·65	4·17
$1\frac{3}{8}$	1·14	1·43	1·72	2·00	2·29	2·87	3·44	4·01	4·59
$1\frac{1}{2}$	1·25	1·56	1·87	2·19	2·50	3·13	3·75	4·38	5·00
$1\frac{5}{8}$	1·35	1·69	2·03	2·37	2·71	3·39	4·07	4·70	5·43
$1\frac{3}{4}$	1·46	1·82	2·19	2·55	2·92	3·65	4·38	5·11	5·84
$1\frac{7}{8}$	1·56	1·95	2·34	2·74	3·13	3·91	4·69	5·47	6·26
2	1·67	2·08	2·50	2·92	3·34	4·17	5·01	5·86	6·68
$2\frac{1}{8}$	1·77	2·21	2·66	3·10	3·55	4·43	5·32	6·21	7·10
$2\frac{1}{4}$	1·87	2·34	2·81	3·28	3·76	4·69	5·63	6·57	7·52
$2\frac{3}{8}$	1·98	2·47	2·97	3·47	3·96	4·95	5·95	6·94	7·93
$2\frac{1}{2}$	2·08	2·60	3·13	3·65	4·17	5·21	6·26	7·30	8·35
$2\frac{5}{8}$	2·19	2·74	3·28	3·83	4·38	5·47	6·57	7·67	8·77
$2\frac{3}{4}$	2·29	2·87	3·44	4·01	4·59	5·74	6·88	8·03	9·18
$2\frac{7}{8}$	2·40	3·00	3·60	4·20	4·80	6·00	7·20	8·40	9·60
3	2·50	3·13	3·75	4·38	5·01	6·26	7·51	8·76	10·02
$3\frac{1}{4}$	2·71	3·39	4·07	4·74	5·43	6·78	8·14	9·49	10·86
$3\frac{1}{2}$	2·92	3·65	4·38	5·11	5·84	7·30	8·76	10·23	11·69
$3\frac{3}{4}$	3·13	3·91	4·68	5·47	6·26	7·82	9·39	10·95	12·52
4	3·34	4·17	5·00	5·84	6·68	8·35	10·02	11·69	13·36
$4\frac{1}{4}$	3·54	4·43	5·32	6·21	7·09	8·87	10·64	12·42	14·19
$4\frac{1}{2}$	3·75	4·69	5·63	6·57	7·51	9·39	11·27	13·15	15·03
$4\frac{3}{4}$	3·96	4·95	5·94	6·94	7·93	9·91	11·89	13·88	15·86
5	4·17	5·21	6·26	7·30	8·35	10·44	12·52	14·61	16·70
$5\frac{1}{4}$	4·38	5·47	6·57	7·67	8·76	10·96	13·14	15·34	17·53
$5\frac{1}{2}$	4·59	5·73	6·88	8·03	9·18	11·48	13·77	16·07	18·37
$5\frac{3}{4}$	4·80	6·00	7·20	8·40	9·60	12·00	14·40	16·80	19·20
6	5·01	6·25	7·51	8·76	10·02	12·53	15·03	17·53	20·05

HOOP IRON.—Dimensions and Weight in lbs. per foot run.

Breadth	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1 in.	$1\frac{1}{8}$	$1\frac{1}{4}$
B. W. gauge	21	20	19	18	17	16
Weight per lineal foot .	·0666	·0875	·1216	·1636	·21	·27
Breadth	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2 in.	$2\frac{1}{4}$	$2\frac{1}{2}$
B. W. gauge	15	15	14	13	13	12
Weight per lineal foot .	·33	·36	·484	·634	·714	·91

WEIGHT OF A LINEAL FOOT OF ROUND AND SQUARE BAR IRON IN LBS.

Diameter or Side.	Square Bars.	Round Bars.	Breadth or Diam. in inches.	Square Bars.	Round Bars.	Breadth or Diam. in inches.	Square Bars.	Round Bars.
$\frac{1}{4}$	·209	·164	$1\frac{1}{4}$	5·25	4·09	3	30·07	23·60
$\frac{5}{16}$	·326	·256	$1\frac{3}{8}$	6·35	4·96	$3\frac{1}{4}$	35·28	27·70
$\frac{3}{8}$	·470	·369	$1\frac{1}{2}$	7·51	5·90	$3\frac{1}{2}$	40·91	32·13
$\frac{7}{16}$	·640	·502	$1\frac{5}{8}$	8·82	6·92	$3\frac{3}{4}$	46·97	36·89
$\frac{1}{2}$	·835	·656	$1\frac{3}{4}$	10·29	8·03	4	53·44	41·97
$\frac{9}{16}$	1·057	·831	$1\frac{7}{8}$	11·74	9·22	$4\frac{1}{4}$	60·32	47·38
$\frac{5}{8}$	1·305	1·025	2	13·36	10·49	$4\frac{1}{2}$	67·63	53·12
$\frac{11}{16}$	1·579	1·241	$2\frac{1}{8}$	15·08	11·84	$4\frac{3}{4}$	75·35	59·18
$\frac{3}{4}$	1·879	1·476	$2\frac{1}{4}$	16·91	13·27	5	83·51	65·58
$\frac{13}{16}$	2·205	1·732	$2\frac{3}{8}$	18·84	14·79	$5\frac{1}{4}$	92·46	72·30
$\frac{7}{8}$	2·556	2·011	$2\frac{1}{2}$	20·87	16·39	$5\frac{1}{2}$	101·03	79·35
$\frac{15}{16}$	2·936	2·306	$2\frac{5}{8}$	23·11	18·07	$5\frac{3}{4}$	110·43	86·73
1	3·34	2·62	$2\frac{3}{4}$	25·26	19·84	6	120·24	94·43
$1\frac{1}{8}$	4·22	3·32	$2\frac{7}{8}$	27·61	21·68	—	—	—

To convert into weight of other metals, multiply tabular No. for cast iron by ·93, for steel × 1·02, for copper × 1·15, for brass × 1·09, for lead × 1·47, for zinc × ·92.

Weight of a Square Foot of Sheet Metals in lbs.
Thickness Birmingham Wire Gauge.

Thickness B.W.G.	Iron.	Copper.	Brass.	Thickness B.W.G.	Iron.	Copper.	Brass.
30	·48	·550	·527	15	2·88	3·298	3·161
29	·52	·595	·579	14	3·32	3·801	3·644
28	·56	·641	·615	13	3·80	4·351	4·170
27	·64	·733	·702	12	4·36	4·992	4·785
26	·72	·824	·790	11	4·80	5·496	5·268
25	·80	·916	·878	10	5·36	6·137	5·883
24	·88	1·008	·966	9	5·92	6·778	6·497
23	1·00	1·145	1·097	8	6·60	7·557	7·243
22	1·12	1·282	1·229	7	7·20	8·244	7·902
21	1·28	1·466	1·405	6	8·12	9·297	8·912
20	1·40	1·603	1·536	5	8·80	10·076	9·658
19	1·68	1·924	1·844	4	9·52	10·900	10·448
18	1·96	2·244	2·151	3	10·36	11·862	11·370
17	2·32	2·656	2·546	2	11·36	13·007	12·468
16	2·60	2·977	2·853	1	12·00	13·740	13·170

Weight of a Superficial Foot of Plates, Different Metals, in lbs.

Thickness Inches.	Iron.	Steel.	Brass.	Copper.	Lead.	Zinc.	Thickness. Inches.	Thickness. Millimètres.
$\frac{1}{16}$	2·5	2·6	2·7	2·9	3·7	2·3	·0625	1·59
$\frac{1}{8}$	5	5·1	5·5	5·8	7·4	4·7	·125	3·17
$\frac{3}{16}$	7·5	7·7	8·2	8·7	11·1	7·0	·1875	4·76
$\frac{1}{4}$	10	10·2	11·0	11·6	14·8	9·4	·25	6·35
$\frac{5}{16}$	12·5	12·8	13·7	14·5	18·5	11·7	·3125	7·94
$\frac{3}{8}$	15	15·3	16·4	17·2	22·2	14·0	·375	9·52
$\frac{7}{16}$	17·5	17·9	19·2	20·0	25·9	16·4	·4375	11·11
$\frac{1}{2}$	20	20·4	21·9	22·9	29·5	18·7	·5	12·7
$\frac{9}{16}$	22·5	23·0	24·6	25·7	33·2	21·1	·5625	14·29
$\frac{5}{8}$	25	25·5	27·4	28·6	36·9	23·4	·625	15·87
$\frac{11}{16}$	27·5	28·1	30·1	31·4	40·6	25·7	·6875	17·46
$\frac{3}{4}$	30	30·6	32·9	34·3	44·3	28·1	·75	19·05
$\frac{13}{16}$	32·5	33·2	35·6	37·2	48·0	30·4	·8125	20·64
$\frac{7}{8}$	35	35·7	38·3	40·0	51·7	32·8	·875	22·22
$\frac{15}{16}$	37·5	38·3	41·2	42·9	55·4	35·1	·9375	23·81
1	40	40·8	43·9	45·8	59·1	37·5	1·000	25·4

Weight of Angle and T Iron.
(By C. H. Jordan, Esq.)

Rule for calculating Weight of ordinary Angle and T Iron.

W = Weight of angle-iron per lineal foot.
B = Breadths of flanges added in decimal parts of a foot.
T = Thickness of angle-iron in decimal parts of a foot.
w = Weight of iron in lbs. per sq. ft. of the thickness of the angle-iron.

$$W = (B - T) \times w.$$

Weights of ⊔ (channel) and H iron may be found from the Tables of Angle and T Iron in the following manner, provided the web and flanges are of the same mean thickness:—

Let the number in the side column of the Tables referred to, equal half the sum of the depth of web, and breadth of both flanges; then twice the weight corresponding thereto will be the weight per lineal foot, according to the thickness, of the channel or H iron required.

Weights of Angle and T Iron in lbs. per Lineal Foot.

Breadths of flanges added. (ins.)	Thickness in Fractions of an inch.								Breadths of flanges added. (ins.)
	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	
2	1·13	1·46	1·76	2·03	—	—	—	—	2
$2\frac{1}{8}$	1·21	1·56	1·89	2·19	—	—	—	—	$2\frac{1}{8}$
$2\frac{1}{4}$	1·29	1·67	2·02	2·34	—	—	—	—	$2\frac{1}{4}$
$2\frac{3}{8}$	1·37	1·77	2·15	2·50	—	—	—	—	$2\frac{3}{8}$
$2\frac{1}{2}$	1·45	1·88	2·28	2·66	3·01	—	—	—	$2\frac{1}{2}$
$2\frac{5}{8}$	1·52	1·98	2·41	2·81	3·19	—	—	—	$2\frac{5}{8}$
$2\frac{3}{4}$	1·60	2·08	2·54	2·97	3·37	—	—	—	$2\frac{3}{4}$
$2\frac{7}{8}$	1·68	2·19	2·67	3·13	3·55	—	—	—	$2\frac{7}{8}$
3	1·76	2·29	2·80	3·28	3·74	4·17	—	—	3
$3\frac{1}{8}$	1·84	2·40	2·93	3·44	3·92	4·37	—	—	$3\frac{1}{8}$
$3\frac{1}{4}$	1·91	2·50	3·06	3·59	4·10	4·58	—	—	$3\frac{1}{4}$
$3\frac{3}{8}$	1·99	2·60	3·19	3·75	4·28	4·79	—	—	$3\frac{3}{8}$
$3\frac{1}{2}$	2·07	2·71	3·32	3·91	4·47	5·00	5·51	—	$3\frac{1}{2}$
$3\frac{5}{8}$	2·15	2·81	3·45	4·06	4·65	5·21	5·74	—	$3\frac{5}{8}$
$3\frac{3}{4}$	2·23	2·92	3·58	4·22	4·83	5·42	5·98	—	$3\frac{3}{4}$
$3\frac{7}{8}$	2·30	3·02	3·71	4·38	5·01	5·63	6·21	—	$3\frac{7}{8}$
4	2·38	3·13	3·84	4·53	5·20	5·83	6·45	7·03	4
$4\frac{1}{8}$	2·46	3·23	3·97	4·69	5·38	6·04	6·68	7·29	$4\frac{1}{8}$
$4\frac{1}{4}$	2·54	3·33	4·10	4·84	5·56	6·25	6·91	7·55	$4\frac{1}{4}$
$4\frac{3}{8}$	2·62	3·44	4·23	5·00	5·74	6·46	7·15	7·81	$4\frac{3}{8}$
$4\frac{1}{2}$	2·70	3·54	4·36	5·16	5·92	6·67	7·38	8·07	$4\frac{1}{2}$

WEIGHTS OF ANGLE AND T IRON IN LBS. PER LINEAL FOOT—*continued.*

Breadths of flanges added. (ins.)	Thickness in Fractions of an inch.														Breadths of flanges added. (ins.)
	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{13}{16}$	$\frac{7}{8}$	$\frac{15}{16}$	1	
$4\frac{5}{8}$	2·77	3·65	4·49	5·31	6·11	6·87	7·62	8·33	9·02	—	—	—	—	—	$4\frac{5}{8}$
$4\frac{3}{4}$	2·85	3·75	4·62	5·47	6·29	7·08	7·85	8·59	9·31	—	—	—	—	—	$4\frac{3}{4}$
$4\frac{7}{8}$	2·93	3·85	4·75	5·62	6·47	7·29	8·09	8·85	9·60	—	—	—	—	—	$4\frac{7}{8}$
5	3·01	3·96	4·88	5·78	6·65	7·50	8·32	9·11	9·88	10·62	—	—	—	—	5
$5\frac{1}{8}$	3·09	4·06	5·01	5·94	6·84	7·71	8·55	9·37	10·17	10·94	—	—	—	—	$5\frac{1}{8}$
$5\frac{1}{4}$	3·16	4·17	5·14	6·09	7·02	7·92	8·79	9·63	10·45	11·25	—	—	—	—	$5\frac{1}{4}$
$5\frac{3}{8}$	3·24	4·27	5·27	6·25	7·20	8·12	9·02	9·90	10·74	11·56	—	—	—	—	$5\frac{3}{8}$
$5\frac{1}{2}$	3·32	4·37	5·40	6·41	7·38	8·33	9·26	10·16	11·03	11·87	12·69	—	—	—	$5\frac{1}{2}$
$5\frac{5}{8}$	3·40	4·48	5·53	6·56	7·56	8·54	9·49	10·42	11·31	12·19	13·03	—	—	—	$5\frac{5}{8}$
$5\frac{3}{4}$	3·48	4·58	5·66	6·72	7·75	8·75	9·73	10·68	11·60	12·50	13·37	—	—	—	$5\frac{3}{4}$
$5\frac{7}{8}$	3·55	4·69	5·79	6·87	7·93	8·96	9·96	10·94	11·89	12·81	13·71	—	—	—	$5\frac{7}{8}$
6	3·63	4·79	5·92	7·03	8·11	9·17	10·19	11·20	12·17	13·12	14·05	14·95	—	—	6
$6\frac{1}{8}$	3·71	4·90	6·05	7·19	8·29	9·37	10·43	11·46	12·46	13·43	14·39	15·31	—	—	$6\frac{1}{8}$
$6\frac{1}{4}$	3·79	5·00	6·18	7·34	8·48	9·58	10·66	11·72	12·74	13·75	14·72	15·67	—	—	$6\frac{1}{4}$
$6\frac{3}{8}$	3·87	5·10	6·32	7·50	8·66	9·79	10·90	11·98	13·03	14·06	15·06	16·04	—	—	$6\frac{3}{8}$
$6\frac{1}{2}$	3·95	5·21	6·45	7·66	8·84	10·00	11·13	12·24	13·32	14·37	15·40	16·40	17·38	—	$6\frac{1}{2}$
$6\frac{5}{8}$	4·02	5·31	6·58	7·81	9·02	10·21	11·37	12·50	13·60	14·68	15·74	16·77	17·77	—	$6\frac{5}{8}$
$6\frac{3}{4}$	4·10	5·42	6·71	7·97	9·21	10·42	11·60	12·76	13·89	15·00	16·08	17·13	18·16	—	$6\frac{3}{4}$
$6\frac{7}{8}$	4·18	5·52	6·84	8·13	9·39	10·63	11·84	13·02	14·18	15·31	16·42	17·50	18·55	—	$6\frac{7}{8}$
7	4·26	5·63	6·97	8·28	9·57	10·83	12·07	13·28	14·47	15·62	16·76	17·86	18·94	20·00	7
$7\frac{1}{8}$	4·34	5·73	7·10	8·44	9·75	11·04	12·30	13·54	14·75	15·93	17·10	18·23	19·34	20·42	$7\frac{1}{8}$

WEIGHTS OF ANGLE AND T IRON IN LBS. PER LINEAL FOOT—*continued.*

Breadths of flanges added. (ins.)	Thickness in Fractions of an inch.														Breadths of flanges added. (ins.)
	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{13}{16}$	$\frac{7}{8}$	$\frac{15}{16}$	1	
$7\frac{1}{4}$	4·41	5·83	7·23	8·59	9·93	11·25	12·54	13·80	15·04	16·25	17·43	18·59	19·73	20·83	$7\frac{1}{4}$
$7\frac{3}{8}$	4·49	5·94	7·36	8·75	10·12	11·46	12·77	14·06	15·33	16·56	17·77	18·96	20·12	21·25	$7\frac{3}{8}$
$7\frac{1}{2}$	4·57	6·04	7·49	8·91	10·30	11·67	13·01	14·32	15·61	16·87	18·11	19·32	20·51	21·67	$7\frac{1}{2}$
$7\frac{5}{8}$	4·65	6·15	7·62	9·06	10·48	11·87	13·24	14·58	15·90	17·19	18·45	19·69	20·90	22·08	$7\frac{5}{8}$
$7\frac{3}{4}$	4·73	6·25	7·75	9·22	10·66	12·08	13·48	14·84	16·18	17·50	18·79	20·05	21·29	22·50	$7\frac{3}{4}$
$7\frac{7}{8}$	4·80	6·35	7·88	9·37	10·85	12·29	13·71	15·10	16·47	17·81	19·13	20·42	21·68	22·92	$7\frac{7}{8}$
8	4·88	6·46	8·01	9·53	11·03	12·50	13·94	15·36	16·76	18·12	19·46	20·78	22·07	23·33	8
$8\frac{1}{8}$	4·96	6·56	8·14	9·69	11·21	12·71	14·18	15·62	17·04	18·44	19·80	21·15	22·46	23·75	$8\frac{1}{8}$
$8\frac{1}{4}$	5·04	6·67	8·27	9·84	11·39	12·92	14·41	15·88	17·33	18·75	20·14	21·51	22·85	24·16	$8\frac{1}{4}$
$8\frac{3}{8}$	5·12	6·77	8·40	10·00	11·57	13·12	14·65	16·15	17·62	19·06	20·48	21·87	23·24	24·58	$8\frac{3}{8}$
$8\frac{1}{2}$	5·20	6·87	8·53	10·16	11·76	13·33	14·88	16·41	17·90	19·37	20·82	22·24	23·63	25·00	$8\frac{1}{2}$
$8\frac{5}{8}$	5·27	6·98	8·66	10·31	11·94	13·54	15·12	16·67	18·19	19·69	21·16	22·60	24·02	25·41	$8\frac{5}{8}$
$8\frac{3}{4}$	5·35	7·08	8·79	10·47	12·12	13·75	15·35	16·93	18·47	20·00	21·49	22·97	24·41	25·83	$8\frac{3}{4}$
$8\frac{7}{8}$	5·43	7·19	8·92	10·62	12·30	13·96	15·58	17·19	18·76	20·31	21·83	23·33	24·80	26·25	$8\frac{7}{8}$
9	5·51	7·29	9·05	10·78	12·49	14·17	15·82	17·45	19·05	20·62	22·17	23·70	25·19	26·66	9
$9\frac{1}{8}$	5·59	7·40	9·18	10·94	12·67	14·37	16·05	17·71	19·33	20·94	22·51	24·06	25·58	27·08	$9\frac{1}{8}$
$9\frac{1}{4}$	5·66	7·50	9·31	11·09	12·85	14·58	16·29	17·97	19·62	21·25	22·85	24·42	25·97	27·50	$9\frac{1}{4}$
$9\frac{3}{8}$	5·74	7·60	9·44	11·25	13·03	14·79	16·52	18·23	19·91	21·56	23·19	24·79	26·36	27·91	$9\frac{3}{8}$
$9\frac{1}{2}$	5·82	7·71	9·57	11·41	13·22	15·00	16·76	18·49	20·19	21·87	23·53	25·15	26·75	28·33	$9\frac{1}{2}$
$9\frac{5}{8}$	5·90	7·81	9·70	11·56	13·40	15·21	16·99	18·75	20·48	22·19	23·87	25·52	27·14	28·75	$9\frac{5}{8}$
$9\frac{3}{4}$	5·98	7·92	9·83	11·72	13·58	15·42	17·23	19·01	20·77	22·50	24·20	25·88	27·54	29·16	$9\frac{3}{4}$

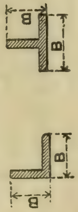
WEIGHTS OF ANGLE AND T IRON IN LBS. PER LINEAL FOOT—*continued.*

Breadths of flanges added. (ins.)	Thickness in Fractions of an inch.													Breadths of flanges added. (ins.)
	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{13}{16}$	$\frac{7}{8}$	$\frac{15}{16}$	1	
$9\frac{7}{8}$	6·05	8·02	9·96	11·87	13·76	15·63	17·46	19·27	21·05	22·81	24·54	26·25	27·93	29·58	$9\frac{7}{8}$
10	6·13	8·13	10·09	12·03	13·95	15·83	17·70	19·53	21·34	23·12	24·88	26·61	28·32	30·00	10
$10\frac{1}{8}$	6·21	8·23	10·22	12·19	14·13	16·04	17·93	19·79	21·63	23·44	25·22	26·98	28·71	30·42	$10\frac{1}{8}$
$10\frac{1}{4}$	6·29	8·33	10·35	12·34	14·31	16·25	18·16	20·05	21·91	23·75	25·56	27·34	29·10	30·83	$10\frac{1}{4}$
$10\frac{3}{8}$	6·37	8·44	10·48	12·50	14·49	16·46	18·40	20·31	22·20	24·06	25·90	27·71	29·49	31·25	$10\frac{3}{8}$
$10\frac{1}{2}$	6·45	8·54	10·61	12·66	14·67	16·67	18·63	20·57	22·49	24·37	26·24	28·07	29·88	31·67	$10\frac{1}{2}$
$10\frac{5}{8}$	6·52	8·65	10·74	12·81	14·86	16·87	18·87	20·83	22·77	24·69	26·57	28·44	30·27	32·08	$10\frac{5}{8}$
$10\frac{3}{4}$	6·60	8·75	10·87	12·97	15·04	17·08	19·10	21·09	23·06	25·00	26·91	28·80	30·66	32·50	$10\frac{3}{4}$
$10\frac{7}{8}$	6·68	8·85	11·00	13·12	15·22	17·29	19·34	21·35	23·35	25·31	27·25	29·17	31·05	32·91	$10\frac{7}{8}$
11	6·76	8·96	11·13	13·28	15·40	17·50	19·57	21·61	23·63	25·62	27·59	29·53	31·45	33·33	11
$11\frac{1}{8}$	—	9·06	11·26	13·44	15·59	17·71	19·80	21·87	23·92	25·94	27·93	29·90	31·84	33·75	$11\frac{1}{8}$
$11\frac{1}{4}$	—	9·17	11·39	13·59	15·77	17·92	20·04	22·13	24·20	26·25	28·27	30·26	32·23	34·17	$11\frac{1}{4}$
$11\frac{3}{8}$	—	9·27	11·52	13·75	15·95	18·12	20·27	22·40	24·49	26·56	28·61	30·62	32·62	34·58	$11\frac{3}{8}$
$11\frac{1}{2}$	—	9·37	11·65	13·91	16·13	18·33	20·51	22·66	24·78	26·87	28·94	30·99	33·01	35·00	$11\frac{1}{2}$
$11\frac{5}{8}$	—	—	11·78	14·06	16·31	18·54	20·74	22·92	25·06	27·19	29·28	31·35	33·40	35·42	$11\frac{5}{8}$
$11\frac{3}{4}$	—	—	11·91	14·22	16·50	18·75	20·98	23·18	25·35	27·50	29·62	31·72	33·79	35·83	$11\frac{3}{4}$
$11\frac{7}{8}$	—	—	12·04	14·37	16·68	18·96	21·21	23·44	25·64	27·81	29·96	32·08	34·18	36·25	$11\frac{7}{8}$
12	—	—	12·17	14·53	16·86	19·17	21·44	23·70	25·92	28·12	30·30	32·45	34·57	36·67	12
$12\frac{1}{8}$	—	—	—	14·69	17·04	19·37	21·68	23·96	26·21	28·44	30·64	32·81	34·96	37·08	$12\frac{1}{8}$
$12\frac{1}{4}$	—	—	—	14·84	17·23	19·58	21·91	24·22	26·50	28·75	30·97	33·17	35·35	37·50	$12\frac{1}{4}$
$12\frac{3}{8}$	—	—	—	15·00	17·41	19·79	22·15	24·48	26·78	29·06	31·31	33·54	35·74	37·92	$12\frac{3}{8}$

WEIGHTS OF ANGLE AND T IRON IN LBS. PER LINEAL FOOT—*continued.*

Breadths of flanges added. (ins.)	Thickness in Fractions of an inch.										Breadths of flanges added. (ins.)
	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{13}{16}$	$\frac{7}{8}$	$\frac{15}{16}$	1	
12½	17·59	20·00	22·38	24·74	27·07	29·37	31·65	33·90	36·13	38·33	12½
12⅝	17·77	20·21	22·62	25·00	27·35	29·69	31·99	34·27	36·52	38·75	12⅝
12¾	17·96	20·42	22·85	25·26	27·64	30·00	32·33	34·63	36·91	39·16	12¾
12⅞	18·14	20·63	23·09	25·52	27·93	30·31	32·67	35·00	37·30	39·58	12⅞
13	18·32	20·83	23·32	25·78	28·22	30·62	33·01	35·36	37·70	40·00	13
13⅛	—	21·04	23·55	26·04	28·50	30·94	33·35	35·73	38·09	40·42	13⅛
13¼	—	21·25	23·79	26·30	28·79	31·25	33·68	36·09	38·48	40·83	13¼
13⅜	—	21·46	24·02	26·56	29·08	31·56	34·02	36·46	38·87	41·25	13⅜
13½	—	21·67	24·26	26·82	29·36	31·87	34·36	36·82	39·26	41·67	13½
13⅝	—	21·87	24·49	27·08	29·65	32·19	34·70	37·19	39·65	42·08	13⅝
13¾	—	22·08	24·73	27·34	29·93	32·50	35·04	37·55	40·04	42·50	13¾
13⅞	—	22·29	24·96	27·60	30·22	32·81	35·38	37·92	40·43	42·91	13⅞
14	—	22·50	25·19	27·86	30·51	33·12	35·72	38·28	40·82	43·33	14
14⅛	—	22·71	25·43	28·12	30·79	33·44	36·05	38·65	41·21	43·75	14⅛
14¼	—	22·92	25·66	28·38	31·08	33·75	36·39	39·01	41·60	44·17	14¼
14⅜	—	23·12	25·90	28·65	31·37	34·06	36·73	39·37	41·99	44·58	14⅜
14½	—	23·33	26·13	28·91	31·65	34·37	37·07	39·74	42·38	45·00	14½
14⅝	—	23·54	26·37	29·17	31·94	34·69	37·41	40·10	42·77	45·42	14⅝
14¾	—	23·75	26·60	29·43	32·22	35·00	37·75	40·47	43·16	45·83	14¾
14⅞	—	23·96	26·83	29·69	32·51	35·31	38·08	40·83	43·55	46·25	14⅞
15	—	24·17	27·07	29·95	32·80	35·62	38·42	41·20	43·95	46·67	15

The added breadths of the flanges B B must be over all as shown in the diagrams:



Sizes and Weight of Sheet Tin.

Mark.	No. of Sheets in a Box.	Dimensions. Length.	Dimensions. Breadth.	Weight of a Box. cwts.	qrs.	lbs.
1 C	225	13¾	10	1	0	0
Hx	225	13¾	10	1	1	7
1x	225	13¾	10	1	1	0
1xx.. ..	225	13¾	10	1	1	21
1xxx ..	225	13¾	10	1	2	14
1xxxx ..	225	13¾	10	1	3	7
D C	100	16¾	12½	0	3	21
Dx	100	16¾	12½	1	0	14
Dxx ..	100	16¾	12½	1	1	7
Dxxx ..	100	16¾	12½	1	2	0
Dxxxx ..	100	16¾	12½	1	2	21
S D C ..	200	15	11	1	2	0
S Dx ..	200	15	11	1	2	21
S Dxx ..	200	15	11	1	3	14
S Dxxx ..	200	15	11	2	0	7
S Dxxxx	200	15	11	2	1	0

Wire.

The Weight of 100 lineal feet.

B. W. Gauge.	Iron.	Steel.	Brass.	Copper.	B. W. Gauge.	Iron.	Steel.	Brass.	Copper.
	lbs.	lbs.	lbs.	lbs.		lbs.	lbs.	lbs.	lbs.
0	30·58	30·92	33·43	35·17	11	4·13	4·18	4·52	4·75
1	25·75	26·04	28·15	29·62	12	3·14	3·18	3·43	3·61
2	21·34	21·57	23·32	24·54	13	2·34	2·36	2·55	2·69
3	18·02	18·22	19·70	20·72	14	1·69	1·71	1·85	1·95
4	15·11	15·28	16·52	17·38	15	1·37	1·39	1·50	1·58
5	12·46	12·59	13·62	14·33	16	1·05	1·06	1·15	1·21
6	11·45	11·57	12·51	13·16	17	·80	·81	·87	·92
7	9·25	9·35	10·11	10·64	18	·61	·62	·67	·70
8	7·29	7·37	7·97	8·38	19	·47	·47	·51	·54
9	6·60	6·68	7·22	7·59	20	·32	·33	·34	·37
10	4·96	5·02	5·43	5·71					

Rule for the Weight of Pipes.

D = Outside diameter of pipe in inches.
d = Inside diameter.
w = Weight of a lineal foot of pipe in lbs.
$w = k\,(D^2 - d^2)$.
k = 2·45 for cast iron.
= 2·64 for wrought iron.
= 2·82 for brass.
= 3·03 for copper.
= 3·86 for lead.

Weight of Cast-iron Pipes

In lbs. per lineal foot. The weight of the two flanges may be reckoned = weight of one foot.

Bore. Inches.	Thickness of Metal.							
	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$
2	8·7	12·3	16·1	—	—	—	—	—
3	12·4	17·1	22·2	—	—	—	—	—
4	16·1	22·1	28·3	—	—	—	—	—
5	19·8	26·9	34·4	42·3	—	—	—	—
6	23·4	31·9	40·6	49·7	—	—	—	—
7	27·1	36·8	46·7	56·8	—	—	—	—
8	30·8	41·6	52·8	64·3	—	—	—	—
9	34·4	46·0	58·9	71·7	—	—	—	—
10	—	51·4	65·1	79	93·3	—	—	—
11	—	56·4	71	86·4	101·8	—	—	—
12	—	—	77·3	93·7	110·4	127·4	—	—
14	—	—	89·6	108·4	127·5	147	—	—
15	—	—	—	115·7	136·1	156·8	177·7	—
16	—	—	—	123·1	144·7	166·6	188·7	—
18	—	—	—	137·9	161·8	186·2	210·8	—
20	—	—	—	—	178·9	205·8	232·9	260·3
22	—	—	—	—	—	225·4	254·9	284·8
24	—	—	—	—	—	245·0	276·9	309·3

WEIGHT OF WROUGHT-IRON GAS-TUBING OF FAIR QUALITY, PER 1000 LINEAL FEET.

Bore.	Weight.	Bore.	Weight.	Bore.	Weight.
in.	cwt.	in.	cwt.	in.	cwt.
$\frac{1}{8}$	2·5	1	16·0	$2\frac{1}{4}$	47·5
$\frac{1}{4}$	3·66	$1\frac{1}{4}$	22·5	$2\frac{1}{2}$	59·6
$\frac{3}{8}$	5·41	$1\frac{1}{2}$	26·5	$2\frac{3}{4}$	75·0
$\frac{1}{2}$	7·77	$1\frac{3}{4}$	35·0	3	82·5
$\frac{3}{4}$	10·5	2	40·0		

WEIGHT OF GAS-TUBING (lbs. per 1000 lineal feet).

Bore in inches	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1
Composition	270	333	438	541	708	1084	1417	1583	1833
Block Tin ..	170	197	230	292	354	480	625	795	980

WEIGHT OF ROUND AND SQUARE COPPER RODS IN LBS. PER LINEAL FOOT.

Size of Rod.	Weight per Lineal Foot.		Size of Rod.	Weight per Lineal Foot.		Size of Rod.	Weight per Lineal Foot.	
	Rnd.	Sqre.		Rnd.	Sqre.		Rnd.	Sqre.
$\frac{1}{4}$	0·19	0·24	$1\frac{1}{8}$	3·86	4·91	2	12·20	15·53
$\frac{5}{16}$	0·30	0·38	$1\frac{3}{16}$	4·30	5·47	$2\frac{1}{16}$	12·97	16·51
$\frac{3}{8}$	0·43	0·55	$1\frac{1}{4}$	4·77	6·06	$2\frac{1}{8}$	13·77	17·53
$\frac{7}{16}$	0·58	0·74	$1\frac{5}{16}$	5·25	6·68	$2\frac{3}{16}$	14·60	18·58
$\frac{1}{2}$	0·76	0·97	$1\frac{3}{8}$	5·77	7·34	$2\frac{1}{4}$	15·44	19·65
$\frac{9}{16}$	0·96	1·23	$1\frac{7}{16}$	6·30	8·02	$2\frac{5}{16}$	16·31	20·76
$\frac{5}{8}$	1·19	1·52	$1\frac{1}{2}$	6·86	8·73	$2\frac{3}{8}$	17·20	21·90
$\frac{11}{16}$	1·44	1·83	$1\frac{9}{16}$	7·45	9·48	$2\frac{7}{16}$	18·12	23·06
$\frac{3}{4}$	1·72	2·18	$1\frac{5}{8}$	8·05	10·25	$2\frac{1}{2}$	19·06	24·26
$\frac{13}{16}$	2·01	2·56	$1\frac{11}{16}$	8·69	11·05	$2\frac{5}{8}$	21·02	26·75
$\frac{7}{8}$	2·33	2·97	$1\frac{3}{4}$	9·34	11·89	$2\frac{3}{4}$	23·07	29·36
$\frac{15}{16}$	2·68	3·41	$1\frac{13}{16}$	10·02	12·75	$2\frac{7}{8}$	25·21	32·09
1	3·05	3·88	$1\frac{7}{8}$	10·72	13·65	3	27·45	34·94
$1\frac{1}{16}$	3·44	4·38	$1\frac{15}{16}$	11·45	14·57			

WEIGHT OF SEAMLESS BRASS TUBES. (Broughton Copper Company.)

		Thickness of Brass.													
Wire Gauge.		7	8	9	10	11	12	13	14	15	16	17	18	19	20
Inches ..		·180	·165	·148	·134	·120	·109	·095	·083	·072	·065	·058	·049	·042	·035
Millimètres		4·57	4·19	3·76	3·40	3·05	2·77	2·41	2·11	1·83	1·65	1·47	1·24	1·07	·89
Ext. Diam.		Weight of a Lineal Foot in Lbs.													
Ins.	Mm.														
$\frac{1}{2}$	12·7	—	—	—	—	—	—	—	—	—	·32	·29	·26	·22	·19
$\frac{5}{8}$	15·9	—	—	—	—	—	—	—	—	·46	·42	·38	·32	·27	·24
$\frac{3}{4}$	19·0	—	—	—	—	—	—	·72	·64	·56	·51	·46	·40	·34	·28
$\frac{7}{8}$	22·2	—	—	—	—	—	·97	·85	·76	·66	·61	·55	·46	·40	·34
1	25·4	—	—	—	—	1·22	1·12	1·00	·88	·77	·69	·64	·54	·46	·39
$1\frac{1}{8}$	28·6	—	—	—	1·55	1·40	1·28	1·13	1·00	·87	·79	·72	·61	·52	—
$1\frac{1}{4}$	31·7	—	—	—	1·74	1·57	1·44	1·27	1·12	·98	·88	·80	·67	·58	—
$1\frac{3}{8}$	34·9	—	—	2·11	1·93	1·75	1·60	1·41	1·24	1·08	·98	·88	·75	—	—
$1\frac{1}{2}$	38·1	—	—	2·32	2·13	1·92	1·76	1·55	1·36	1·19	1·07	·97	·82	—	—
$1\frac{5}{8}$	41·3	—	2·78	2·54	2·32	2·09	1·92	1·63	1·48	1·29	1·17	1·05	—	—	—
$1\frac{3}{4}$	44·4	—	3·02	2·74	2·52	2·27	2·07	1·82	1·60	1·40	1·26	1·14	—	—	—
$1\frac{7}{8}$	47·6	3·54	3·27	2·96	2·71	2·44	2·23	1·96	1·72	1·50	1·36	1·22	—	—	—
2	50·8	3·80	3·50	3·17	2·91	2·61	2·38	2·10	1·84	1·60	1·45	1·30	—	—	—
$2\frac{1}{8}$	54·0	4·07	3·74	3·39	3·10	2·78	2·55	2·23	1·97	1·71	1·55	1·39	—	—	—
$2\frac{1}{4}$	57·1	4·32	3·98	3·61	3·29	2·96	2·71	2·37	2·08	1·81	1·64	1·48	—	—	—
x		·74	·64	·50	·41	·33	·27	·21	·16	·12	·10	·08	·06	·05	·03

Weight of Brass Tubes—*continued.*

B.W.G.		5	6	7	8	9	10	11	12	13	14	15	16
Ins.	Mm.	Weight of a Lineal Foot in Lbs.											
2⅜	60·3	5·49	5·10	4·58	4·22	3·82	3·49	3·13	2·86	2·51	2·20	1·92	1·73
2½	63·5	5·81	5·40	4·84	4·45	4·04	3·68	3·31	3·02	2·65	2·33	2·02	1·82
2⅝	66·7	6·13	5·69	5·10	4·70	4·25	3·88	3·49	3·18	2·78	2·44	2·12	1·92
2¾	69·8	6·45	5·98	5·37	4·94	4·46	4·07	3·66	3·33	2·93	2·56	2·22	2·01
2⅞	73·0	6·76	6·28	5·62	5·18	4·67	4·26	3·83	3·50	3·06	2·69	2·33	2·11
3	76·2	7·09	6·57	5·89	5·41	4·89	4·45	4·01	3·65	3·20	2·80	2·43	2·20
3⅛	79·3	7·40	6·87	6·15	5·65	5·11	4·65	4·18	3·80	3·34	2·93	2·54	2·30
3¼	82·5	7·72	7·16	6·40	5·89	5·32	4·84	4·35	3·97	3·48	3·05	2·64	2·39
3⅜	85·7	8·04	7·46	6·66	6·13	5·53	5·04	4·52	4·13	3·62	3·17	2·74	2·49
3½	88·9	8·36	7·75	6·92	6·37	5·75	5·23	4·70	4·28	3·75	3·29	2·85	2·58
3⅝	92·0	8·68	8·05	7·19	6·61	5·96	5·42	4·87	4·44	3·89	3·40	2·95	2·68
3¾	95·2	9·00	8·34	7·45	6·85	6·17	5·61	5·04	4·60	4·03	3·52	3·06	2·77
3⅞	98·4	9·31	8·63	7·71	7·09	6·39	5·80	5·22	4·75	4·16	3·65	3·16	2·86
4	101·6	9·63	8·93	7·97	7·32	6·60	6·00	5·40	4·91	4·30	3·77	3·27	2·95
x		1·12	0·96	0·74	0·64	0·50	0·41	0·33	0·27	0·21	0·16	0·12	0·10

If the internal diameter is given, add x. For example: the weight per lineal foot of a brass tube 2 inches internal diameter 12 W.G. is $2·38 + 0·27 = 2·65$ lbs.

To ascertain the weight of a seamless tube of other metal, multiply the weight of a similar brass tube by 1·05 for copper, 0·90 for wrought iron, 0·84 for cast iron, or by 1·34 for lead.

f full; *b* bare.

Weight of a Lineal Foot of Wrought-iron Pipe.

Bore in inches.	Thickness of Metal in inches.						Bore in inches.
	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	
$\frac{1}{4}$	·207	·496	·867	1·321	1·857	2·476	$\frac{1}{4}$
$\frac{3}{8}$	·288	·660	1·114	1·649	2·268	2·970	$\frac{3}{8}$
$\frac{1}{2}$	·371	·825	1·361	1·980	2·682	3·465	$\frac{1}{2}$
$\frac{5}{8}$	·454	1·090	1·609	2·310	3·094	3·960	$\frac{5}{8}$
$\frac{3}{4}$	·536	1·154	1·856	2·640	3·506	4·455	$\frac{3}{4}$
$\frac{7}{8}$	·619	1·320	2·103	2·969	3·919	4·950	$\frac{7}{8}$
1	·701	1·485	2·351	3·300	4·331	5·445	1
$1\frac{1}{2}$	1·030	2·144	3·341	4·620	5·981	7·425	$1\frac{1}{2}$
2	1·361	2·805	4·331	5·940	7·631	9·405	2
$2\frac{1}{2}$	1·692	3·465	5·321	7·259	9·281	11·385	$2\frac{1}{2}$
3	2·021	4·125	6·311	8·590	10·931	13·365	3
Bore.	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	Bore.

Weight of Copper Pipes in lbs. per foot lineal.

Bore. Inch.	Thickness in parts of inch. $\frac{1}{16}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{4}$
½	·42	·94	1·60	2·27
¾	·62	1·33	2·17	3·02
1	·79	1·69	2·66	3·77
1½	1·15	2·44	3·85	5·30
2	1·55	3·21	5·00	6·80
2½	1·94	3·97	6·13	8·31
3	2·3	4·73	7·24	9·84

Weight of Lead Pipes in lbs. per foot lineal.

Bore. Inch.	Common.	Middling.	Strong.
	lbs.	lbs.	lbs.
½	1·07	—	—
¾	1·6	1·8	2
1	2·0	2·6	2·8
1¼	3·0	3·7	4·4
1½	4·0	4·7	5·6
2	5·0	6·0	7·0
2½	7·0	8·6	10·0

Weight of Cast-iron Balls and Solid Cylinders in lbs.

Diameter in inches ..	1	2	3	4	5	6	7	8	9
Cast-iron balls	·136	1·10	3·70	8·7	17·1	29·5	47	70	100
Cast-iron cylinder 1 ft. long.. ..	2·4	9·9	21·9	39·0	61·0	89·0	120	156	198

Weight of Nuts and Bolt-heads in lbs.

Diameter of bolt in inches ..	¼	⅜	½	⅝	¾	⅞
Weight of hexagon nut and head	·017	·057	·135	·261	·45	·72
Weight of square nut and head	·021	·071	·169	·330	·57	·90

Diam. of bolt in inches ..	1	1¼	1½	1¾	2	2½	3
Weight of hexagon nut and head	1·07	2·09	3·61	5·7	8·56	17	28·8
Weight of square nut and head	1·35	2·63	4·55	7·2	10·8	21	36·4

D = diameter of bolt in inches.
W = weight of nut and head in lbs.
$W = 1·07\,D^3$ for hexagon $= 1·35\,D^3$ for square.

WEIGHT AND STRENGTH OF ROPES.

C = Circumference of rope in inches.
L = Working load of rope in tons.
S = Breaking strain " "
W = Weight of rope in lbs. per fathom.

$$C = \sqrt{\frac{L}{k}};\ L = C^2 k;\ S = C^2 x;\ W = C^2 y;\ \text{or} = L z.$$

TABLE OF VALUE OF k, x, y, AND z.

Description of Rope.	k	x	y	z
Common hemp	·032	·18	·18	6·
Coir, hawser laid	—	—	·131	—
" cable laid	—	—	·117	—
St. Petersburg tarred hemp, hawser	·037	·22	·235	6·35
" " " cable ..	·025	·15	·207	8·28
White Manilla, hawser	·045	·27	·177	3·93
" " cable	·033	·19	·155	4·70
Best hemp, "cold register"	·100	·60	—	—
" warm..	·116	·70	—	—
Iron wire rope	·290	1·80	·87	2·9
Steel wire rope	·450	2·80	·89	1·91

TABLE OF WORKING STRENGTH OF ROPES IN TONS.

Circum. Inches.	Hemp.		Wire		Circum. Inches.	Hemp.	
	Common.	Good.	Iron.	Steel.		Common.	Good.
1	·032	·046	·29	·45	4¼	·578	·831
1¼	·050	·072	·45	·70	4½	·648	·932
1½	·072	·104	·65	1·01	4¾	·722	1·038
1¾	·098	·141	·89	1·38	5	·800	1·150
2	·128	·184	1·16	1·80	5½	·968	1·392
2¼	·162	·233	1·47	2·28	6	1·152	1·656
2½	·200	·288	1·81	2·81	6½	1·352	1·944
2¾	·242	·348	2·19	3·40	7	1·568	2·254
3	·288	·414	2·61	4·05	7½	1·800	2·588
3¼	·338	·486	3·06	4·75	8	2·048	2·944
3½	·392	·564	3·55	5·51	8½	2·312	3·324
3¾	·450	·647	4·08	6·33	9	2·592	3·726
4	·512	·736	4·64	7·20	10	3·200	4·600

TABLE OF WEIGHT OF ROPES IN LBS. PER FATHOM.

Circum. Inches.	Hemp.		Wire.		Circum. Inches.	Hemp.	
	Common.	Good.	Iron.	Steel.		Common.	Good.
1	·18	·24	·87	·89	4¼	3·25	4·34
1¼	·28	·38	1·36	1·39	4½	3·65	4·86
1½	·41	·54	1·96	2·00	4¾	4·06	5·42
1¾	·55	·74	2·66	2·73	5	4·50	6·00
2	·72	·96	3·48	3·56	5½	5·45	7·26
2¼	·91	1·22	4·40	4·51	6	6·48	8·64
2½	1·13	1·50	5·44	5·56	6½	7·61	10·14
2¾	1·36	1·82	6·58	6·73	7	8·82	11·76
3	1·62	2·16	7·83	8·01	7½	10·13	13·50
3¼	1·90	2·54	9·19	9·40	8	11·52	15·36
3½	2·21	2·94	10·66	10·90	8½	13·05	17·34
3¾	2·53	3·38	12·23	12·52	9	14·58	19·44
4	2·88	3·84	13·92	14·24	10	18·00	24·00

WEIGHT AND STRENGTH OF FLAT ROPES OF HEMP AND WIRE.

Hemp.		Iron Wire.		Steel Wire.		Equivalent Strength.	
Size in inches.	Lbs. weight per fathom.	Size in inches.	Lbs. weight per fathom.	Size in inches.	Lbs. weight per fathom.	Working Load per cwt.	Breaking Strain per ton.
4 × 1⅛	20	2¼ × ½	11	—	—	44	20
5 × 1¼	24	2½ × ½	13	—	—	52	23
5½ × 1⅜	26	2¾ × ⅝	15	—	—	60	27
5¾ × 1½	28	3 × ⅝	16	2 × ½	10	64	28
6 × 1½	30	3¼ × ⅝	18	2¼ × ½	11	72	32
7 × 1⅞	36	3½ × ⅝	20	—	—	80	36
8¼ × 2⅛	40	3¾ × 11/16	22	2½ × ½	13	88	40
8½ × 2¼	45	4 × 11/16	25	2¾ × ⅜	15	100	45
9 × 2½	50	4¼ × ¾	28	3 × ⅜	16	112	50
9½ × 2⅜	55	4½ × ¾	32	3¼ × ⅜	18	128	56
10 × 2½	60	4⅝ × ¾	34	3½ × ⅜	20	136	60

SAFE LOAD ON CHAINS.

D = Diameter in eighths of an inch.
W = Safe load in tons.

$D = \sqrt{9 W}$.

$W = \frac{D^2}{9} = 7 \cdot 111\, d^2$, where

d = Diameter of iron in inches.

TABLE OF WORKING LOAD OF CHAINS.

Diam. ins.	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$
Loa ..	·44	·70	1·0	1·36	1·78	2·25	2·78	3·36	4·0
Diam. ins.	$\frac{13}{16}$	$\frac{7}{8}$	$\frac{15}{16}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{3}{4}$
Load ..	4·69	5·44	6·25	7·11	9	11·11	13·44	16·0	21·78

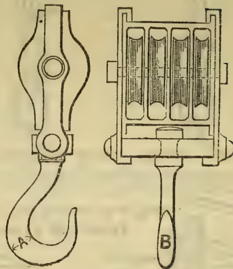
MESSRS. BROWN, LENNOX, AND CO.'S CHAIN CABLE.

Tonnage of Ship.	Diam. of Cable.	Length of Cable.	Average Weight per Fathom.	Proof Strain of Stud Chain Cable.	Weight of Anchor	Approved equivalent Circumference of Rope.
tons.	inches.	fathoms.	lbs.	tons.	cwts.	inches.
25	$\frac{1}{2}$	120	14	$4\frac{1}{2}$	2	$4\frac{3}{4}$
35	$\frac{9}{16}$	120	17	$5\frac{1}{2}$	$2\frac{1}{2}$	$5\frac{1}{2}$
45	$\frac{5}{8}$	120	21	7	$2\frac{3}{4}$	$6\frac{1}{4}$
50	$\frac{11}{16}$	120	25	$8\frac{1}{2}$	3	7
75	$\frac{3}{4}$	120	30	$10\frac{1}{8}$	$3\frac{1}{2}$	$7\frac{3}{4}$
100	$\frac{13}{16}$	150	35	—	5	$8\frac{1}{2}$
150	$\frac{15}{16}$	180	48	—	$7\frac{1}{2}$	10
175	1	180	54	18	9	$10\frac{3}{4}$
250	$1\frac{1}{8}$	210	68	$22\frac{3}{4}$	$12\frac{1}{4}$	12
350	$1\frac{1}{4}$	240	84	$28\frac{1}{8}$	17	$13\frac{1}{2}$
450	$1\frac{3}{8}$	270	102	34	21	15
600	$1\frac{1}{2}$	270	122	$40\frac{1}{2}$	26	16
800	$1\frac{5}{8}$	300	143	$47\frac{1}{2}$	32	$17\frac{1}{4}$
1000	$1\frac{3}{4}$	300	166	$55\frac{1}{8}$	38	$18\frac{1}{2}$
1400	$1\frac{7}{8}$	300	191	$63\frac{1}{4}$	43	—
1800	2	300	217	72	48	—
2500	$2\frac{1}{8}$	330	244	$81\frac{1}{4}$	53	—
3000	$2\frac{1}{4}$	360	268	$91\frac{1}{8}$	57	—

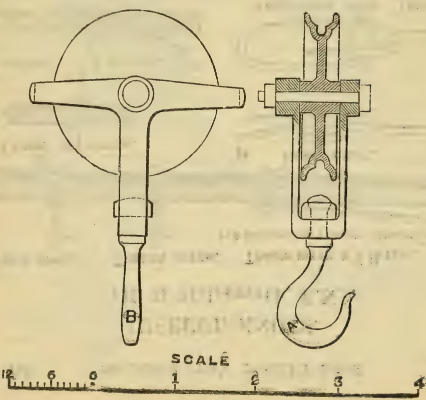
4 Sheave Block for 15-ton Crane.

Size of Metal in Hooks.

Working Load. Tons.	A.	B.
1	$1\frac{3}{4}$	$1\frac{3}{8}$
2	2	$1\frac{1}{2}$
3	$2\frac{1}{8}$	$1\frac{1}{2}$
4	$2\frac{1}{4}$	$1\frac{1}{2}$
5	$2\frac{1}{2}$	$1\frac{1}{2}$
6	$2\frac{3}{4}$	$1\frac{1}{2}$
8	3	$1\frac{3}{4}$
10	$3\frac{1}{4}$	2
12	$3\frac{5}{8}$	2
15	$3\frac{7}{8}$	2
20	$4\frac{1}{2}$	$2\frac{1}{4}$

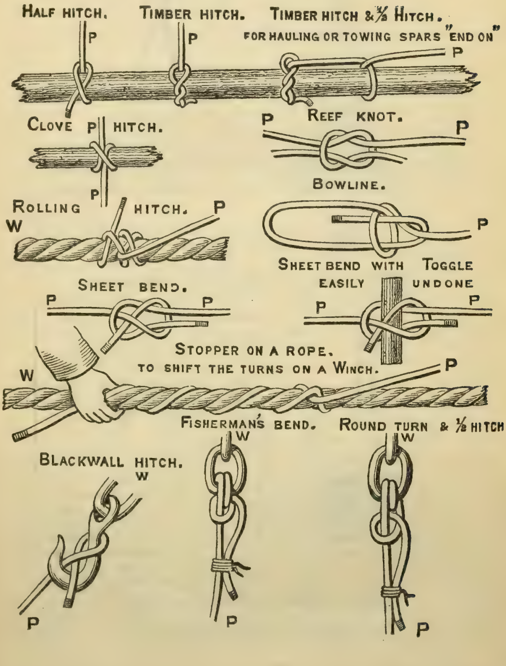


Single Sheave Pulley for 12-ton Crane.



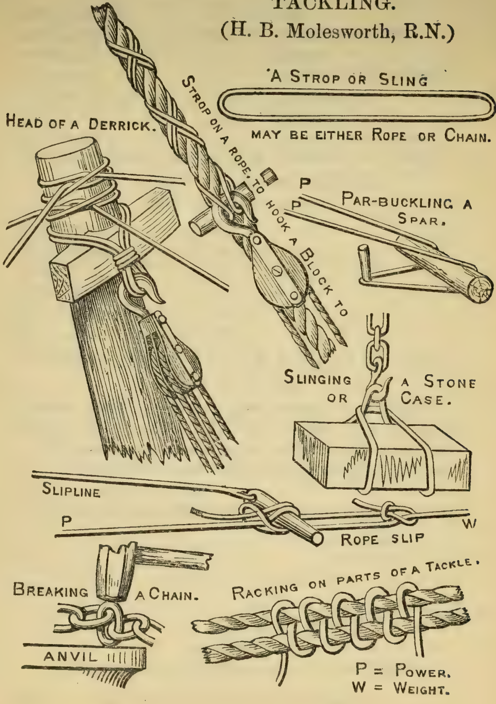
USEFUL KNOTS.

(H. B. Molesworth, R.N.)

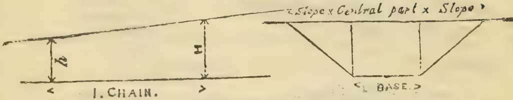


TACKLING.

(H. B. Molesworth, R.N.)



FORMULÆ FOR CONSTRUCTING TABLES OF EARTHWORK.



H and h = the heights of section in feet at each end of a chain length.

C = cubic contents of 1 chain length in YARDS.

The two slopes are taken separately from the central part—the former as frustum of a pyramid 1 chain long, the latter the frustum of a wedge.

FOR BOTH SLOPES.

Frustum of pyramid $C = X \times (H^2 + h^2 + H h)$.

$X = \cdot 204$ in slopes $\frac{1}{4}$ to 1.
$X = \cdot 408$ „ $\frac{1}{2}$ to 1.
$X = \cdot 815$ „ 1 to 1.
$X = 1 \cdot 223$ „ $1\frac{1}{2}$ to 1.
$X = 1 \cdot 629$ „ 2 to 1.
$X = 2 \cdot 445$ „ 3 to 1.

FOR CENTRAL PART.

$C = k\,(H + h)$ frustum of wedge.

$k = 19 \cdot 56$ when base = 16 ft. (Occupation roads).
$k = 22 \cdot 00$ „ = 18 „ Single line railway.
$k = 24 \cdot 45$ „ = 20 „ Ditto.
$k = 34 \cdot 23$ „ = 28 „ Public road.
$k = 36 \cdot 67$ „ = 30 „ Double line railway
$k = 40 \cdot 34$ „ = 33 „ Ditto.
$k = 46 \cdot 45$ „ = 38 „ Turnpike road.
$k = 1 \cdot 2222$ B „ = B in feet.

PRISMOIDAL FORMULA.

$$\frac{[\text{Sum of areas of both ends} + (\text{area of middle} \times 4)] \times \text{length}}{6}$$

Earthwork Table A (Gunter's Chain = 66 feet).

Height in feet.	Contents of 1 chain length of central portion in cube yards for Bases of							Contents of 1 chain length of both Slopes in cube yards for Slopes of					Height in feet.
	1 foot.	16 feet.	18 feet.	20 feet.	28 feet.	30 feet.	33 feet.	¼ to 1.	½ to 1.	1 to 1.	1½ to 1.	2 to 1.	
1	2·4	39	44	49	68	73	81	¾	1¼	2½	3¾	5	1
2	4·9	78	88	98	137	147	161	2½	5	10	15	20	2
3	7·3	117	132	147	205	220	242	5½	11	22	33	44	3
4	9·8	156	176	196	274	293	323	10	20	39	59	78	4
5	12·2	196	220	244	342	367	403	15	31	61	92	122	5
6	14·7	235	264	293	411	440	484	22	44	88	132	176	6
7	17·1	274	308	342	479	513	565	30	60	120	180	240	7
8	19·6	313	352	391	548	587	645	39	78	156	234	313	8
9	22·0	352	396	440	616	660	726	50	99	198	297	396	9
10	24·4	391	440	489	684	733	807	61	122	244	366	489	10
11	26·9	430	484	538	753	807	887	74	148	296	444	592	11
12	29·3	469	528	587	821	880	968	88	176	352	528	704	12
13	31·8	508	572	636	890	953	1049	103	207	413	620	826	13
14	34·2	548	616	684	958	1027	1129	120	240	479	719	958	14
15	36·7	587	660	733	1027	1100	210	138	275	550	825	1100	15
16	39·1	626	704	782	1095	1173	1291	156	313	626	939	1252	16
17	41·6	665	748	831	1164	1247	1371	177	353	706	1059	1413	17
	1 foot.	16 feet.	18 feet.	20 feet.	28 feet.	30 feet.	33 feet.	¼ to 1.	½ to 1.	1 to 1.	1½ to 1.	2 to 1.	
	Width of Base in feet.							Slopes.					

EARTHWORK TABLE A (Gunter's Chain = 66 feet)—*continued.*

Height in feet.	Contents of 1 chain length of central portion in cube yards for Bases of							Contents of 1 chain length of both Slopes in cube yards for Slopes of					Height in feet.
	1 foot.	16 feet.	18 feet.	20 feet.	28 feet.	30 feet.	33 feet.	$\frac{1}{4}$ to 1.	$\frac{1}{2}$ to 1.	1 to 1.	$1\frac{1}{2}$ to 1.	2 to 1.	
18	44·0	704	792	880	1232	1320	1452	198	396	792	1188	1534	18
19	46·4	743	836	929	1300	1393	1533	221	441	882	1323	1765	19
20	48·9	782	880	978	1369	1467	1613	244	489	978	1467	1956	20
21	51·3	821	924	1027	1437	1540	1694	270	539	1078	1617	2156	21
22	53·8	860	968	1076	1506	1613	1775	296	592	1183	1775	2366	22
23	56·2	900	1012	1124	1574	1687	1855	323	647	1293	1940	2586	23
24	58·7	939	1056	1173	1643	1760	1936	352	704	1408	2112	2816	24
25	61·1	978	1100	1222	1711	1833	2017	382	764	1528	2292	3056	25
26	63·6	1017	1144	1271	1780	1907	2097	413	826	1652	2478	3305	26
27	66·0	1056	1188	1320	1848	1980	2178	446	891	1782	2673	3564	27
28	68·4	1095	1232	1369	1916	2053	2259	479	958	1916	2874	3833	28
29	70·9	1134	1276	1418	1985	2127	2339	514	1028	2056	3084	4112	29
30	73·3	1173	1320	1467	2053	2200	2420	550	1100	2200	3300	4400	30
31	75·8	1212	1364	1516	2122	2273	2501	587	1175	2349	3524	4698	31
32	78·2	1252	1408	1564	2190	2347	2581	626	1252	2503	3755	5006	32
33	80·7	1291	1452	1613	2259	2420	2662	666	1331	2662	3993	5324	33
34	83·1	1330	1496	1662	2327	2493	2743	706	1413	2826	4239	5652	34
	1 foot.	16 feet.	18 feet.	20 feet.	28 feet.	30 feet.	33 feet.	$\frac{1}{4}$ to 1.	$\frac{1}{2}$ to 1.	1 to 1.	$1\frac{1}{2}$ to 1.	2 to 1.	
	Width of Base in feet.							Slopes.					

Earthwork Table A (Gunter's Chain = 66 feet)—*continued.*

Height in feet.	Contents of 1 chain length of central portion in cube yards for Bases of							Contents of 1 chain length of both Slopes in cube yards for Slopes of					Height in feet.
	1 foot.	16 feet.	18 feet.	20 feet.	28 feet.	30 feet.	33 feet.	¼ to 1.	½ to 1.	1 to 1.	1½ to 1.	2 to 1.	
35	85·6	1369	1540	1711	2396	2567	2823	749	1497	2994	4491	5989	35
36	88·0	1408	1584	1760	2464	2640	2904	792	1584	3168	4752	6336	36
37	90·4	1447	1628	1809	2532	2713	2985	837	1673	3346	5019	6693	37
38	92·9	1486	1672	1858	2601	2787	3065	882	1765	3530	5295	7060	38
39	95·3	1525	1716	1907	2669	2860	3146	930	1859	3718	5577	7436	39
40	97·8	1564	1760	1956	2738	2933	3227	978	1956	3911	5867	7822	40
41	100·2	1604	1804	2004	2806	3007	3307	1027	2055	4109	6164	8218	41
42	102·7	1643	1848	2053	2875	3080	3388	1078	2156	4312	6468	8624	42
43	105·1	1682	1892	2102	2943	3153	3469	1130	2260	4520	6780	9040	43
44	107·6	1721	1936	2151	3012	3227	3549	1183	2366	4732	7098	9465	44
45	110·0	1760	1980	2200	3080	3300	3630	1238	2475	4950	7425	9900	45
46	112·4	1799	2024	2249	3148	3373	3711	1293	2586	5172	7758	10345	46
47	114·9	1838	2068	2298	3217	3447	3791	1350	2700	5400	8100	10800	47
48	117·3	1877	2112	2347	3285	3520	3872	1408	2816	5632	8448	11264	48
49	119·8	1916	2156	2396	3354	3593	3953	1467	2934	5869	8803	11738	49
50	122·2	1956	2200	2444	3422	3667	4033	1528	3055	6111	9166	12222	50
	1 foot.	16 feet.	18 feet.	20 feet.	28 feet.	30 feet.	33 feet.	¼ to 1.	½ to 1.	1 to 1.	1½ to 1.	2 to 1.	
	Width of Base in feet.							Slopes.					

For any other bases multiply the quantity due to 1 foot base by the width of base required.

EARTHWORK TABLE B.

Contents of 1 foot length in cubic feet (for lengths of 100 feet alter two places of decimals).

Height in feet.	Central portion. Width of Base in feet.							Contents of both Slopes.							Height in feet.
	10 ft.	16 ft.	18 ft.	20 ft.	28 ft.	30 ft.	33 ft.	¼ to 1.	½ to 1.	¾ to 1.	1 to 1.	1½ to 1.	2 to 1.	3 to 1.	
1	10	16	18	20	28	30	33	·25	·5	·75	1	1·5	2	3	1
2	20	32	36	40	56	60	66	1	2	3	4	6	8	12	2
3	30	48	54	60	84	90	99	2·25	4·5	6·75	9	13·5	18	27	3
4	40	64	72	80	112	120	132	4	8	12	16	24	32	48	4
5	50	80	90	100	140	150	165	6·25	12·5	18·75	25	37·5	50	75	5
6	60	96	108	120	168	180	198	9	18	27	36	54	72	108	6
7	70	112	126	140	196	210	231	12·25	24·5	36·75	49	73·5	98	147	7
8	80	128	144	160	224	240	264	16	32	48	64	96	128	192	8
9	90	144	162	180	252	270	297	20·25	40·5	60·75	81	121·5	162	243	9
10	100	160	180	200	280	300	330	25	50	75	100	150	200	300	10
11	110	176	198	220	308	330	363	30·25	60·5	90·75	121	181·5	242	363	11
12	120	192	216	240	336	360	396	36	72	108	144	216	288	432	12
13	130	208	234	260	364	390	429	42·25	84·5	126·75	169	253·5	338	507	13
14	140	224	252	280	392	420	462	49	98	147	196	294	392	588	14
15	150	240	270	300	420	450	495	56·25	112·5	168·75	225	337·5	450	675	15
16	160	256	288	320	448	480	528	64	128	192	256	384	512	768	16
17	170	272	306	340	476	510	561	72·25	144·5	216·75	289	433·5	578	867	17
Height in feet.	10 ft.	16 ft.	18 ft.	20 ft.	28 ft.	30 ft.	33 ft.	¼ to 1.	½ to 1.	¾ to 1.	1 to 1.	1½ to 1.	2 to 1.	3 to 1.	Height in feet.
	Central portion. Width of Base in feet.							Both Slopes.							

EARTHWORK TABLE B—*continued.*

Contents of 1 foot length in cubic feet (for lengths of 100 feet alter two places of decimals).

Height in feet.	Central portion. Width of Base in feet.							Contents of both Slopes.							Height in feet.
	10 ft.	16 ft.	18 ft.	20 ft.	28 ft.	30 ft.	33 ft.	$\frac{1}{4}$ to 1.	$\frac{1}{2}$ to 1.	$\frac{3}{4}$ to 1.	1 to 1.	$1\frac{1}{2}$ to 1.	2 to 1.	3 to 1.	
18	180	288	324	360	504	540	594	81	162	243	324	486	648	972	18
19	190	304	342	380	532	570	627	90·25	180·5	270·75	361	541·5	722	1083	19
20	200	320	360	400	560	600	660	100	200	300	400	600	800	1200	20
21	210	336	378	420	588	630	693	110·25	220·5	330·75	441	661·5	882	1323	21
22	220	352	396	440	616	660	726	121	242	363	484	726	968	1452	22
23	230	368	414	460	644	690	759	132·25	264·5	396·75	529	793·5	1058	1587	23
24	240	384	432	480	672	720	792	144	288	432	576	864	1152	1728	24
25	250	400	450	500	700	750	825	156·25	312·5	468·75	625	937·5	1250	1875	25
26	260	416	468	520	728	780	858	169	338	507	676	1014	1352	2028	26
27	270	432	486	540	756	810	891	182·25	364·5	546·75	729	1093·5	1458	2187	27
28	280	448	504	560	784	840	924	196	392	588	784	1176	1568	2352	28
29	290	464	522	580	812	870	957	210·25	420·5	630·75	841	1261·5	1682	2523	29
30	300	480	540	600	840	900	990	225	450	675	900	1350	1800	2700	30
31	310	496	558	620	868	930	1023	240·25	480·5	720·75	961	1441·5	1922	2883	31
32	320	512	576	640	896	960	1056	256	512	768	1024	1536	2048	3072	32
33	330	528	594	660	924	990	1089	272·25	544·5	816·75	1089	1633·5	2178	3267	33
34	340	544	612	680	952	1020	1122	289	578	867	1156	1734	2312	3468	34
Height in feet.	10 ft.	16 ft.	18 ft.	20 ft.	28 ft.	30 ft.	33 ft.	$\frac{1}{4}$ to 1.	$\frac{1}{2}$ to 1.	$\frac{3}{4}$ to 1.	1 to 1.	$1\frac{1}{2}$ to 1.	2 to 1.	3 to 1.	Height in feet
	Central portion. Width of Base in feet.							Both Slopes.							

EARTHWORK TABLE B—*continued.*

Contents of 1 foot length in cubic feet (for lengths of 100 feet alter two places of decimals).

Height in feet.	Central portion. Width of Base in feet.							Contents of both Slopes.							Height in feet.
	10 ft.	16 ft.	18 ft.	20 ft.	28 ft.	30 ft.	33 ft.	¼ to 1.	½ to 1.	¾ to 1.	1 to 1.	1½ to 1.	2 to 1.	3 to 1.	
35	350	560	630	700	980	1050	1155	306·25	612·5	918·75	1225	1837·5	2450	3675	35
36	360	576	648	720	1008	1080	1188	324	648	972	1296	1944	2592	3888	36
37	370	592	666	740	1036	1110	1221	342·25	684·5	1026·75	1369	2053·5	2738	4107	37
38	380	608	684	760	1064	1140	1254	361	722	1083	1444	2166	2888	4332	38
39	390	624	702	780	1092	1170	1287	380·25	760·5	1140·75	1521	2281·5	3042	4563	39
40	400	640	720	800	1120	1200	1320	400	800	1200	1600	2400	3200	4800	40
41	410	656	738	820	1148	1230	1353	420·25	840·5	1260·75	1681	2521·5	3362	5043	41
42	420	672	756	840	1176	1260	1386	441	882	1323	1764	2646	3528	5292	42
43	430	688	774	860	1204	1290	1419	462·25	924·5	1386·75	1849	2773·5	3698	5547	43
44	440	704	792	880	1232	1320	1452	484	968	1452	1936	2904	3872	5808	44
45	450	720	810	900	1260	1350	1485	506·25	1012·5	1518·75	2025	3037·5	4050	6075	45
46	460	736	828	920	1288	1380	1518	529	1058	1587	2116	3174	4232	6348	46
47	470	752	846	940	1316	1410	1551	552·25	1104·5	1656·75	2209	3313·5	4418	6627	47
48	480	768	864	960	1344	1440	1584	576	1152	1728	2304	3456	4608	6912	48
49	490	784	882	980	1372	1470	1617	600·25	1200·5	1800·75	2401	3601·5	4802	7203	49
50	500	800	900	1000	1400	1500	1650	625	1250	1875	2500	3750	5000	7500	50
Height in feet.	10 ft.	16 ft.	18 ft.	20 ft.	28 ft.	30 ft.	33 ft.	¼ to 1.	½ to 1.	¾ to 1.	1 to 1.	1½ to 1.	2 to 1.	3 to 1.	Height in feet.
	Central portion. Width of Base in feet.							Both Slopes.							

Earthwork Tables A and B.

The first set of tables (A) is applicable to the English practice, in which the height is given in feet, the length in Gunter's chain of 66 feet, and the contents in cubic yards. The second set (B) is applicable to any measure when the length, height, and contents are all of the same unit.

Quantities of earthwork may be calculated with sufficient accuracy for all practical purposes by these tables, unless the heights at each end of the length differ greatly when a correction for the slopes is necessary.

If H and h be the tabular numbers for the slopes at each end of a length respectively, the cubic contents $= x\ (H + h)$. (For values of x, see table.) On sidelong ground where the areas are taken out from cross sections, if A and a be the areas of a slope at each end respectively, the cubic contents of the slope $= y\ (A + a)$. (For values of y, see table.)

Values of x to be used for Slopes only.

50	·5					
40	·4959	·5				
30	·4804	·4933	·5			
20	·4483	·4667	·4872	·5		
10	·3973	·4118	·4333	·4667	·5	
5	·3663	·3742	·3870	·4118	·4667	·5
0	·3333	·3333	·3333	·3333	·3333	·3333
Feet	50	40	30	20	10	5

EARTHWORK TABLES—*continued.*

VALUES OF y FOR FIRST SET OF TABLES A.

If A ÷ a =	0	·05	·1	·15	·2	·25	·3	·35
y =	·8148	·9884	1·049	1·089	1·185	1·141	1·158	1·172
If A ÷ a =	·4	·45	·5	·6	·7	·8	·9	1·0
y =	1·183	1·192	1·199	1·209	1·216	1·219	1·222	1·222

VALUES OF y FOR SECOND SET OF TABLES B.

If A ÷ a =	0	·05	·1	·15	·2	·25	·3	·35
y =	·3333	·4043	·4292	·4456	·4576	·4667	·4738	·4794
If A ÷ a =	·4	·45	·5	·6	·7	·8	·9	1·0
y =	·4839	·4876	·4905	·4947	·4974	·4990	·4998	·5

MEASUREMENT OF EARTHWORK. (Hurst.)

To measure the solidity over large areas of irregular depth. Divide the surface into triangles, and multiply the area of each by one-third of the sum of the depths taken at the angles, and the result will equal the solidity.

EARTHWORK TABLES. (General De Lisle, R.E.)

Tables I. and II. give the cubic contents of a prismoid in terms of the unit of measurement, that is cubic mètres from mètres, cubic feet from feet, cubic inches from inches, &c.

Tables III. and IV. are adapted for English railway practice, giving cubic yards from measurements in feet.

Tables V. and VI. give the correction for difference of width when the latter is not uniform from end to end of the prismoid, and are to be used with any of the first four Tables.

2. In all these Tables the argument is the decimal corresponding to $\frac{\text{lesser height}}{\text{greater height}} = \frac{h}{\text{H}}$ $= v$, of which the first place is to be found in the left-hand column, the second at the top of the columns, and the difference for the third is found by simple interpolation.

3. The dimensions must in all cases be those which give the true area of the end sections as shown in Figs. 1, 2, 3, 4, where in Fig. 1 H is the mean of the two side heights $h\ h'$; in Fig. 2, W is the mean of the top and bottom heights. In the end sections of a prismoid, the greater height or width is denoted by a capital letter.

4. To find the true mean width W_m when the width is not uniform.

EARTHWORK TABLES—*continued.*

FIG. 1.

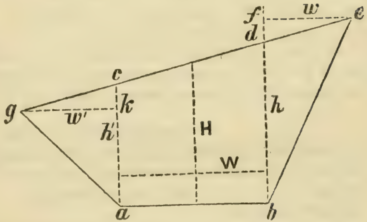


FIG. 2.

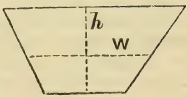


FIG. 3.

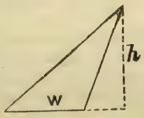
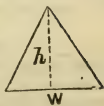


FIG. 4.



1. When the greater width is at the same end as the greater height. Enter Table V. with the argument $v = \frac{h}{\text{H}}$, and take

EARTHWORK TABLES—*continued.*

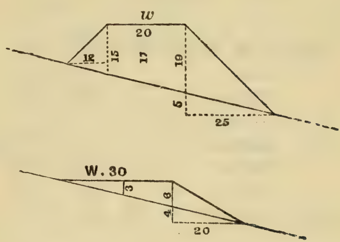
out the factor F, which multiply by the difference of the two widths; add the result to the lesser width to find W_m.

2. When the greater width and greater height are at different ends. Proceed in exactly the same manner as above, but use Table VI. instead of Table V.

Example.

Let the figures represent the end sections of a portion of embankment 55 feet long.

FIG. 5.



Left Slope.

$$v = \frac{h}{H} = \frac{0}{15} = \cdot 00; \ F = \cdot 667, \text{ Table V.}$$

EARTHWORK TABLES—*continued.*

$$W_m = 20 + (W - w)F = 0 + (12 - 0)\ 667 = 8.$$

$$\begin{array}{rrcl} v = & \cdot 00\ N_2 & = & \bar{1}\cdot 3979 \text{ Table II.*} \\ H = & 15 & = & 1\cdot 1761 \\ L = & 55 & = & 1\cdot 7404 \\ W_m = & 8 & = & 0\cdot 9031 \\ \hline V = & 1650 & = & 3\cdot 2175 \end{array}$$

By direct calculation, V = 1650.

Centre.

$$v = \frac{h}{H} = \frac{3}{17} = \cdot 177;\ f = \cdot 383, \text{ Table VI.†}$$

$$W_m = w + (W - w)f = 20 + (30 - 20)\cdot 383 = 23\cdot 83.$$

$$\begin{array}{rrcl} v = & \cdot 177\ N_1 & = & \bar{1}\cdot 7697 \text{ Table I.} \\ H = & 17 & = & 1\cdot 2304 \\ L = & 55 & = & 1\cdot 7404 \\ W_m = & 23\cdot 83 & = & 1\cdot 3772 \\ \hline V = & 13110 & = & 4\cdot 1177 \end{array}$$

By direct calculation, V = 13108·33.

* Triangular Prismoid: N from Table II.

† W at lower end, Table VI. is required.

EARTHWORK TABLES—*continued.*

Right Slope.

$$v = \frac{h}{H} = \frac{6}{19} = \cdot 316\,;\ F = \cdot 587,\ \text{Table V.}$$

$$W - w = 25 - 20 = 5\,;\ 5 \times \cdot 587 = 2\cdot 93.$$

$$w + (W - w)\,F = 20 + 2\cdot 93 = 22\cdot 93 = W_m.$$

$$\begin{array}{rlcl} v = & \cdot 316\ N_2 & = & \bar{1}\cdot 5172\ \text{Table II.*} \\ H = & 19 & = & 1\cdot 2788 \\ L = & 55 & = & 1\cdot 7404 \\ W_m = & 22\cdot 93 & = & 1\cdot 3604 \\ \hline V = & 7884 & = & 3\cdot 8968 \end{array}$$

By direct calculation, $V = 7883\cdot 3$.

Whole volume of embankment = 1650 + 13110 + 7884 = 22644 cubic mètres, yards, or feet, supposing the dimensions to be in mètres, yards, or feet respectively. By direct calculation the result is 22642 nearly.

In this example the right-hand slopes are "*in winding*" to show that the Tables are quite general in their application, and only require that the correct dimensions for area of end sections shall be used.

Tables I., II., III., IV., are from equations by Mr. Ryan, formerly of Messrs. Cameron and Ryan, Bombay.

Tables V., VI., are from equations by the Rev. J. Sowerby, formerly of Marlborough College.

* Triangular Prismoid: N from Table II.

EARTHWORK TABLES. (General De Lisle, R.E.)

I.

TRAPEZOIDAL PRISMOIDS. LOGS. Length, unity; Width, unity.

v	·00		·01		·02		·03		·04		·05		·06		·07		·08		·09	
·0	$\bar{1}$·6990	43	$\bar{1}$·7033	43	$\bar{1}$·7076	42	$\bar{1}$·7118	42	$\bar{1}$·7160	42	$\bar{1}$·7202	41	$\bar{1}$·7243	40	$\bar{1}$·7283	41	$\bar{1}$·7324	40	$\bar{1}$·7364	40
·1	$\bar{1}$·7404	39	$\bar{1}$·7443	39	$\bar{1}$·7482	38	$\bar{1}$·7520	39	$\bar{1}$·7559	38	$\bar{1}$·7597	37	$\bar{1}$·7634	37	$\bar{1}$·7671	37	$\bar{1}$·7708	37	$\bar{1}$·7745	36
·2	$\bar{1}$·7781	36	$\bar{1}$·7817	36	$\bar{1}$·7853	36	$\bar{1}$·7889	35	$\bar{1}$·7924	35	$\bar{1}$·7959	34	$\bar{1}$·7993	35	$\bar{1}$·8028	34	$\bar{1}$·8062	34	$\bar{1}$·8096	33
·3	$\bar{1}$·8129	33	$\bar{1}$·8162	33	$\bar{1}$·8195	33	$\bar{1}$·8228	33	$\bar{1}$·8261	32	$\bar{1}$·8293	32	$\bar{1}$·8325	32	$\bar{1}$·8357	31	$\bar{1}$·8388	32	$\bar{1}$·8420	31
·4	$\bar{1}$·8451	31	$\bar{1}$·8482	31	$\bar{1}$·8513	30	$\bar{1}$·8543	30	$\bar{1}$·8573	30	$\bar{1}$·8603	30	$\bar{1}$·8633	30	$\bar{1}$·8663	29	$\bar{1}$·8692	30	$\bar{1}$·8722	29
·5	$\bar{1}$·8751	28	$\bar{1}$·8779	29	$\bar{1}$·8808	29	$\bar{1}$·8837	28	$\bar{1}$·8865	28	$\bar{1}$·8893	28	$\bar{1}$·8921	28	$\bar{1}$·8949	27	$\bar{1}$·8976	28	$\bar{1}$·9004	27
·6	$\bar{1}$·9031	27	$\bar{1}$·9058	27	$\bar{1}$·9085	27	$\bar{1}$·9112	26	$\bar{1}$·9138	26	$\bar{1}$·9164	27	$\bar{1}$·9191	26	$\bar{1}$·9217	26	$\bar{1}$·9243	26	$\bar{1}$·9269	25
·7	$\bar{1}$·9294	26	$\bar{1}$·9320	25	$\bar{1}$·9345	25	$\bar{1}$·9370	25	$\bar{1}$·9395	25	$\bar{1}$·9420	25	$\bar{1}$·9445	24	$\bar{1}$·9469	25	$\bar{1}$·9494	24	$\bar{1}$·9518	24
·8	$\bar{1}$·9542	24	$\bar{1}$·9566	24	$\bar{1}$·9590	24	$\bar{1}$·9614	24	$\bar{1}$·9638	23	$\bar{1}$·9661	24	$\bar{1}$·9685	23	$\bar{1}$·9708	23	$\bar{1}$·9731	23	$\bar{1}$·9754	23
·9	$\bar{1}$·9777	23	$\bar{1}$·9800	23	$\bar{1}$·9823	22	$\bar{1}$·9845	23	$\bar{1}$·9868	22	$\bar{1}$·9890	22	$\bar{1}$·9912	22	$\bar{1}$·9934	22	$\bar{1}$·9956	22	$\bar{1}$·9978	22
1·	0·0000																			

$H \times L \times W_m \times N_1 = V$ in Cube of unit of measure.

W_m = mean Width. N_n, tabular Number; n, number of Table. V, volume of Prismoid.

Earthwork Tables—*continued.*

II.

Triangular Prismoids. Logs. Length, unity; Width, unity.

v	·00		·01		·02		·03		·04		·05		·06		·07		·08		·09	
·0	$\bar{1}$·3979	44	$\bar{1}$·4023	43	$\bar{1}$·4066	42	$\bar{1}$·4108	42	$\bar{1}$·4150	41	$\bar{1}$·4191	41	$\bar{1}$·4232	41	$\bar{1}$·4273	41	$\bar{1}$·4314	40	$\bar{1}$·4354	39
·1	$\bar{1}$·4393	40	$\bar{1}$·4433	39	$\bar{1}$·4472	38	$\bar{1}$·4510	38	$\bar{1}$·4548	38	$\bar{1}$·4586	38	$\bar{1}$·4624	37	$\bar{1}$·4661	37	$\bar{1}$·4698	37	$\bar{1}$·4735	36
·2	$\bar{1}$·4771	36	$\bar{1}$·4807	36	$\bar{1}$·4843	35	$\bar{1}$·4878	36	$\bar{1}$·4914	35	$\bar{1}$·4949	34	$\bar{1}$·4983	34	$\bar{1}$·5017	34	$\bar{1}$·5051	34	$\bar{1}$·5085	34
·3	$\bar{1}$·5119	33	$\bar{1}$·5152	33	$\bar{1}$·5185	33	$\bar{1}$·5218	32	$\bar{1}$·5250	33	$\bar{1}$·5283	32	$\bar{1}$·5315	32	$\bar{1}$·5347	31	$\bar{1}$·5378	32	$\bar{1}$·5410	31
·4	$\bar{1}$·5441	31	$\bar{1}$·5472	30	$\bar{1}$·5502	31	$\bar{1}$·5533	30	$\bar{1}$·5563	30	$\bar{1}$·5593	30	$\bar{1}$·5623	30	$\bar{1}$·5653	29	$\bar{1}$·5682	29	$\bar{1}$·5711	29
·5	$\bar{1}$·5740	29	$\bar{1}$·5769	29	$\bar{1}$·5798	28	$\bar{1}$·5826	29	$\bar{1}$·5855	28	$\bar{1}$·5883	28	$\bar{1}$·5911	27	$\bar{1}$·5938	28	$\bar{1}$·5966	27	$\bar{1}$·5993	28
·6	$\bar{1}$·6021	27	$\bar{1}$·6048	27	$\bar{1}$·6075	26	$\bar{1}$·6101	27	$\bar{1}$·6128	26	$\bar{1}$·6154	27	$\bar{1}$·6181	26	$\bar{1}$·6207	26	$\bar{1}$·6233	25	$\bar{1}$·6258	26
·7	$\bar{1}$·6284	25	$\bar{1}$·6309	26	$\bar{1}$·6335	25	$\bar{1}$·6360	25	$\bar{1}$·6385	25	$\bar{1}$·6410	25	$\bar{1}$·6435	24	$\bar{1}$·6459	25	$\bar{1}$·6484	24	$\bar{1}$·6508	24
·8	$\bar{1}$·6532	24	$\bar{1}$·6556	24	$\bar{1}$·6580	24	$\bar{1}$·6604	24	$\bar{1}$·6628	23	$\bar{1}$·6651	24	$\bar{1}$·6675	23	$\bar{1}$·6698	23	$\bar{1}$·6721	23	$\bar{1}$·6744	23
·9	$\bar{1}$·6767	23	$\bar{1}$·6790	22	$\bar{1}$·6812	23	$\bar{1}$·6835	22	$\bar{1}$·6857	23	$\bar{1}$·6880	22	$\bar{1}$·6902	22	$\bar{1}$·6924	22	$\bar{1}$·6946	22	$\bar{1}$·6968	22
1·	$\bar{1}$·6990																			

$H \times L \times W_m \times N_2 = V$ in Cube of unit of measure.

H . h, Greater and less Heights. L, length of Prismoid. W . w, Greater and less Widths.

Earthwork Tables—*continued.*

III.

Trapezoidal Prismoids. Logs. Length, one foot; Width, one foot.

v	·00		·01		·02		·03		·04		·05		·06		·07		·08		·09	
·0	$\bar{2}$·2676	43	$\bar{2}$·2719	43	$\bar{2}$·2762	42	$\bar{2}$·2804	42	$\bar{2}$·2846	42	$\bar{2}$·2888	41	$\bar{2}$·2929	41	$\bar{2}$·2970	40	$\bar{2}$·3010	40	$\bar{2}$·3050	40
·1	$\bar{2}$·3090	39	$\bar{2}$·3129	39	$\bar{2}$·3168	39	$\bar{2}$·3207	38	$\bar{2}$·3245	38	$\bar{2}$·3283	38	$\bar{2}$·3321	37	$\bar{2}$·3358	37	$\bar{2}$·3395	37	$\bar{2}$·3432	36
·2	$\bar{2}$·3468	36	$\bar{2}$·3504	36	$\bar{2}$·3540	35	$\bar{2}$·3575	35	$\bar{2}$·3610	35	$\bar{2}$·3645	35	$\bar{2}$·3680	34	$\bar{2}$·3714	34	$\bar{2}$·3748	34	$\bar{2}$·3782	34
·3	$\bar{2}$·3816	33	$\bar{2}$·3849	33	$\bar{2}$·3882	33	$\bar{2}$·3915	32	$\bar{2}$·3947	32	$\bar{2}$·3979	32	$\bar{2}$·4011	32	$\bar{2}$·4043	32	$\bar{2}$·4075	31	$\bar{2}$·4106	31
·4	$\bar{2}$·4137	31	$\bar{2}$·4168	31	$\bar{2}$·4199	31	$\bar{2}$·4230	30	$\bar{2}$·4260	30	$\bar{2}$·4290	30	$\bar{2}$·4320	29	$\bar{2}$·4349	30	$\bar{2}$·4379	29	$\bar{2}$·4408	29
·5	$\bar{2}$·4437	29	$\bar{2}$·4466	28	$\bar{2}$·4494	29	$\bar{2}$·4523	28	$\bar{2}$·4551	28	$\bar{2}$·4579	28	$\bar{2}$·4607	28	$\bar{2}$·4635	28	$\bar{2}$·4663	27	$\bar{2}$·4690	27
·6	$\bar{2}$·4717	27	$\bar{2}$·4744	27	$\bar{2}$·4771	27	$\bar{2}$·4798	26	$\bar{2}$·4824	27	$\bar{2}$·4851	26	$\bar{2}$·4877	26	$\bar{2}$·4903	26	$\bar{2}$·4929	26	$\bar{2}$·4955	26
·7	$\bar{2}$·4981	25	$\bar{2}$·5006	25	$\bar{2}$·5031	26	$\bar{2}$·5057	25	$\bar{2}$·5082	24	$\bar{2}$·5106	25	$\bar{2}$·5131	25	$\bar{2}$·5156	24	$\bar{2}$·5180	25	$\bar{2}$·5205	24
·8	$\bar{2}$·5229	24	$\bar{2}$·5253	24	$\bar{2}$·5277	24	$\bar{2}$·5301	23	$\bar{2}$·5324	24	$\bar{2}$·5348	23	$\bar{2}$·5371	23	$\bar{2}$·5394	24	$\bar{2}$·5418	23	$\bar{2}$·5441	23
·9	$\bar{2}$·5464	22	$\bar{2}$·5486	23	$\bar{2}$·5509	23	$\bar{2}$·5532	22	$\bar{2}$·5554	22	$\bar{2}$·5576	23	$\bar{2}$·5599	22	$\bar{2}$·5621	22	$\bar{2}$·5643	22	$\bar{2}$·5665	21
1·	$\bar{2}$·5686																			

$$H \times L \times W_m \times N_3 = V \text{ in Cubic Yards.}$$

W_m = mean Width. N_n, tabular Number; n, number of Table. V, volume of Prismoid.

Earthwork Tables—*continued.*

IV.

Triangular Prismoids.				Logs.			Length, one foot; Width, one foot.			
v	·00	·01	·02	·03	·04	·05	·06	·07	·08	·09
·0	$\bar{3}$·9666 43	$\bar{3}$·9709 43	$\bar{3}$·9752 42	$\bar{3}$·9794 42	$\bar{3}$·9836 42	$\bar{3}$·9878 41	$\bar{3}$·9919 41	$\bar{3}$·9960 40	$\bar{2}$·0000 40	$\bar{2}$·0040 40
·1	$\bar{2}$·0080 39	$\bar{2}$·0119 39	$\bar{2}$·0158 39	$\bar{2}$·0197 38	$\bar{2}$·0235 38	$\bar{2}$·0273 37	$\bar{2}$·0310 38	$\bar{2}$·0348 37	$\bar{2}$·0385 36	$\bar{2}$·0421 37
·2	$\bar{2}$·0458 36	$\bar{2}$·0494 35	$\bar{2}$·0529 36	$\bar{2}$·0565 35	$\bar{2}$·0600 35	$\bar{2}$·0635 35	$\bar{2}$·0670 34	$\bar{2}$·0704 34	$\bar{2}$·0738 34	$\bar{2}$·0772 33
·3	$\bar{2}$·0805 33	$\bar{2}$·0838 33	$\bar{2}$·0871 33	$\bar{2}$·0904 33	$\bar{2}$·0937 32	$\bar{2}$·0969 32	$\bar{2}$·1001 32	$\bar{2}$·1033 32	$\bar{2}$·1065 31	$\bar{2}$·1096 31
·4	$\bar{2}$·1127 31	$\bar{2}$·1158 31	$\bar{2}$·1189 30	$\bar{2}$·1219 30	$\bar{2}$·1249 30	$\bar{2}$·1279 30	$\bar{2}$·1309 30	$\bar{2}$·1339 29	$\bar{2}$·1368 30	$\bar{2}$·1398 29
·5	$\bar{2}$·1427 29	$\bar{2}$·1456 28	$\bar{2}$·1484 29	$\bar{2}$·1513 28	$\bar{2}$·1541 28	$\bar{2}$·1569 28	$\bar{2}$·1597 28	$\bar{2}$·1625 27	$\bar{2}$·1652 28	$\bar{2}$·1680 27
·6	$\bar{2}$·1707 27	$\bar{2}$·1734 27	$\bar{2}$·1761 27	$\bar{2}$·1788 26	$\bar{2}$·1814 27	$\bar{2}$·1841 26	$\bar{2}$·1867 26	$\bar{2}$·1893 26	$\bar{2}$·1919 26	$\bar{2}$·1945 25
·7	$\bar{2}$·1970 26	$\bar{2}$·1996 25	$\bar{2}$·2021 25	$\bar{2}$·2046 25	$\bar{2}$·2071 25	$\bar{2}$·2096 25	$\bar{2}$·2121 25	$\bar{2}$·2146 24	$\bar{2}$·2170 24	$\bar{2}$·2194 25
·8	$\bar{2}$·2219 24	$\bar{2}$·2243 23	$\bar{2}$·2266 24	$\bar{2}$·2290 24	$\bar{2}$·2314 23	$\bar{2}$·2337 24	$\bar{2}$·2361 23	$\bar{2}$·2384 23	$\bar{2}$·2407 23	$\bar{2}$·2430 23
·9	$\bar{2}$·2453 23	$\bar{2}$·2476 23	$\bar{2}$·2499 22	$\bar{2}$·2521 23	$\bar{2}$·2544 22	$\bar{2}$·2566 22	$\bar{2}$·2588 22	$\bar{2}$·2610 22	$\bar{2}$·2632 22	$\bar{2}$·2654 22
1·	$\bar{2}$·2676									

$$H \times L \times W_m \times N_4 = V \text{ in Cubic Yards.}$$

H . h, Greater and less Heights. L, length of Prismoid. W . w, Greater and less Widths.

V.

Factor F for difference of Width.							Decimals.					Greater Width W at higher end H.								
v	·00		·01		·02		·03		·04		·05		·06		·07		·08		·09	
·0	·667	4	·663	3	·660	3	·657	3	·654	3	·651	3	·648	3	·645	3	·642	3	·639	3
·1	·636	2	·634	3	·631	3	·628	2	·626	3	·623	2	·621	3	·618	2	·616	3	·613	2
·2	·611	2	·609	2	·607	3	·604	2	·602	2	·600	2	·598	2	·596	2	·594	2	·592	2
·3	·590	2	·588	2	·586	2	·584	2	·582	2	·580	2	·578	1	·577	2	·575	2	·573	2
·4	·571	1	·570	2	·568	2	·566	1	·565	2	·563	1	·562	2	·560	1	·559	2	·557	1
·5	·556	2	·554	1	·553	2	·551	1	·550	2	·548	1	·547	1	·546	2	·544	1	·543	1
·6	·542	2	·540	1	·539	1	·538	1	·537	2	·535	1	·534	1	·533	1	·532	1	·531	2
·7	·529	1	·528	1	·527	1	·526	1	·525	1	·524	1	·523	1	·522	1	·521	1	·520	1
·8	·519	1	·518	1	·517	1	·516	1	·515	1	·514	1	·513	1	·512	1	·511	1	·510	1
·9	·509	1	·508	1	·507	1	·506	1	·505	1	·504	1	·503	1	·502	0	·502	1	·501	1
1·	·500																			

$$W_m = w + (W - w)F.$$

W_m = mean Width. N_n, tabular Number; *n*, number of Table. V, volume of Prismoid.

EARTHWORK TABLES—*continued.*

VI.

Factor f for difference of Width.							DECIMALS.						Greater Width W at lower end h.							
v	·00		·01		·02		·03		·04		·05		·06		·07		·08		·09	
·0	·333	4	·337	3	·340	3	·343	3	·346	3	·349	3	·352	3	·355	3	·358	3	·361	3
·1	·364	2	·366	3	·369	3	·372	2	·374	3	·377	2	·379	3	·382	2	·384	3	·387	2
·2	·389	2	·391	2	·393	3	·396	2	·398	2	·400	2	·402	2	·404	2	·406	2	·408	2
·3	·410	2	·412	2	·414	2	·416	2	·418	2	·420	2	·422	1	·423	2	·425	2	·427	2
·4	·429	1	·430	2	·432	2	·434	1	·435	2	·437	1	·438	2	·440	1	·441	2	·443	1
·5	·444	2	·446	1	·447	2	·449	1	·450	2	·452	1	·453	1	·454	2	·456	1	·457	1
·6	·458	2	·460	1	·461	1	·462	1	·463	2	·465	1	·466	1	·467	1	·468	1	·469	2
·7	·471	1	·472	1	·473	1	·474	1	·475	1	·476	1	·477	1	·478	1	·479	1	·480	1
·8	·481	1	·482	1	·483	1	·484	1	·485	1	·486	1	·487	1	·488	1	·489	1	·490	1
·9	·491	1	·492	1	·493	1	·494	1	·495	1	·496	1	·497	1	·498	0	·498	1	·499	1
1·	·500																			

$$W_m = w + (W - w)f.$$

H . h, Greater and less Heights. L, length of Prismoid. W . w Greater and less Widths.

EARTHWORK TABLES. (General De Lisle, R.E.)

Half Cutting, Half Bank.

Express the ratios of hill slope and back cutting or bank slope in terms of $\frac{\text{base}}{\text{height}}$, let the difference of these ratios for cutting $= c$, for bank $= b$, and let $\frac{\text{area bank}}{\text{area cutting}} = r$.

Then if $\frac{b}{c\,r}$ is less than unity, its value taken as argument for Table VII. gives K_c, a factor which multiplied by the whole width of the road gives the width for *cutting*.

But if $\frac{b}{c\,r}$ is greater than unity, its reciprocal as argument in Table VII. gives K_b, a factor which, multiplied by the whole width of the road, gives the width for bank.

When $r = 1$, that is, when cutting and bank are to be equal, the arguments are $\frac{b}{c}$ or $\frac{c}{b}$ respectively.

Examples.

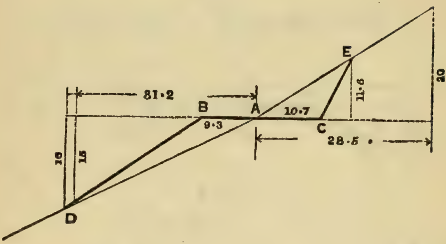
Let width of road $= 20$ feet.

$$r = \frac{\text{bank}}{\text{cutting}} = 1 \cdot 2.$$

EARTHWORK TABLES—*continued.*

Cutting.	Bank.
Hill slope $\frac{28 \cdot 5}{20} = 1 \cdot 425$	Hill slope $\frac{31 \cdot 2}{15} = 2 \cdot 08$
Back slope $\frac{\frac{1}{2}}{1} = \cdot 5$	Bank slope $\frac{1 \cdot 5}{1} = 1 \cdot 50$
$c = \cdot 925$	$b = 0 \cdot 58$

FIG. 6.



$$\frac{b\,r}{c} = \frac{\cdot 58 \times 1 \cdot 2}{\cdot 925} = \cdot 753; \text{ Table VII., } K_c = \cdot 535.$$

$$20 \times \ 535 = 10 \cdot 7, \text{width for cutting; } h = \frac{10 \cdot 7}{\cdot 925} = 11 \cdot 6.$$

$$20 - 10\ \ 7 = 9 \cdot 3, \text{ width for bank; } h' = \frac{9\ \ 3}{\cdot 58} = 16.$$

$$\text{Areas } \frac{\text{A B D}}{\text{A E C}} = \frac{9 \cdot 3 \times 16}{10 \cdot 7 \times 11 \cdot 6} = 1 \cdot 2 = r \text{ nearly.}$$

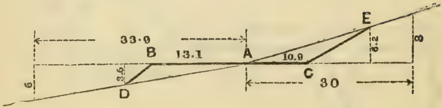
EARTHWORK TABLES—*continued.*

Let width of road = 24 feet.

$r \doteq {}^{\cdot}70.$

Cutting.	Bank.
Hill slope $\frac{30}{8} = 3{\cdot}75$	Hill slope $\frac{33{\cdot}9}{6} = 5\ 65$
Back slope $\frac{2}{1} = 2{\cdot}$	Bank slope 2
$c = 1{\cdot}75$	$b = 3{\cdot}65$

FIG. 7.



In this case $\frac{b\,r}{c}$ is greater than unity.

$$\frac{c}{b\,r} = \frac{1{\cdot}75}{3{\cdot}65 \times {\cdot}70} = {\cdot}685;$$

Table VII., $K_b = {\cdot}547$.

$24 \times {\cdot}547 = 13{\cdot}1$, width for bank; $h' = \frac{13{\cdot}1}{3{\cdot}65} = 3\ 6$

$24 - 13{\cdot}1 = 10{\cdot}9$, width for cutting; $h = \frac{10{\cdot}9}{1{\cdot}75} = 6\ 2.$

$$\text{Areas } \frac{\text{A B D}}{\text{A C E}} = \frac{13{\cdot}1 \times 3{\cdot}6}{10{\cdot}9 \times 6{\cdot}2} = \ 7 = r$$

Table VII. is from an equation by General W. Scott, R.E. (late Bombay).

Earthwork Tables. (General De Lisle, R.E.)

VII.

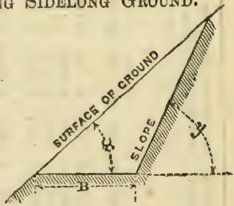
Half Cutting, Half Bank.										Decimals.		Factor K_b for width of Bank, or Factor K_c for width of Cutting.								
u or u'	0		1		2		3		4		5		6		7		8		9	
·0	1·000	91	·909	33	·876	24	·852	19	·833	16	·817	14	·803	12	·791	12	·779	10	·769	9
·1	·760	9	·751	8	·743	8	·735	7	·728	7	·721	7	·714	6	·708	6	·702	6	·696	5
·2	·691	5	·686	5	·681	5	·676	5	·671	4	·667	5	·662	4	·658	4	·654	4	·650	4
·3	·646	4	·642	4	·638	3	·635	3	·632	4	·628	3	·625	3	·622	3	·619	3	·616	3
·4	·613	3	·610	3	·607	3	·604	3	·601	3	·598	2	·596	3	·593	2	·591	3	·588	2
·5	·586	3	·583	2	·581	2	·579	3	·576	2	·574	2	·572	2	·570	2	·568	2	·566	3
·6	·563	2	·561	2	·559	2	·557	2	·555	2	·553	1	·552	2	·550	2	·548	2	·546	2
·7	·544	1	·543	2	·541	2	·539	2	·537	1	·536	2	·534	2	·533	2	·531	2	·529	1
·8	·528	2	·526	1	·525	2	·523	1	·522	2	·520	1	·519	2	·517	1	·516	1	·515	2
·9	·513	1	·512	2	·510	1	·509	1	·508	2	·506	1	·505	1	·504	1	·503	2	·501	1
1·	·500																			

If $c > br$, $u = \frac{br}{c}$ and $W \times K_c$ = width of Cutting, w_c. Then $w_b = W - w_c$. W = formation width.

If $br > c$, $u' = \frac{c}{br}$ and $W \times K_b$ = width of Bank, w_b. Then $w_c = W - w_b$.

Roads Skirting Sidelong Ground.

B = Width of base.
A = Area of section.
x = Angle of ground with horizon.
y = Angle of slope with horizon.



$$A = \frac{1}{2}\left(\frac{B^2}{\text{cotan. } x - \text{cotan. } y}\right) = B^2 K.$$

Angle of ground x.	Values of K for different Slopes.				
	¼ to 1.	½ to 1.	¾ to 1.	1 to 1.	1½ to 1.
10	·0922	·0967	·1016	·107	·1199
12	·1123	·119	·1265	·1351	·1562
14	·1329	·1424	·1533	·1661	·1992
16	·1543	·1672	·1794	·2008	·2512
18	·1766	·1937	·2145	·2407	·3164
20	·2	·2222	·25	·2857	·4009
22	·2252	·2538	·2907	·3389	·5128
24	·25	·2857	·3342	·4012	·6702
26	·2777	·3225	·3846	·4761	·909
28	·3067	·362	·4421	·5675	1·3123
30	·3373	·4058	·5091	·6830	2·1551
32	·3703	·4545	·5882	·8333	
34	·4058	·5091	·6830	1·0373	
36	·444	·5707	·7987	1·3297	
38	·4854	·641	·9434	1·7857	
40	·5307	·7225	1·131	2·6041	
42	·5807	·8183	1·385		
44	·6364	·9345	1·754		
46	·6983	1·0729	2·315		
48	·7692	1·25			
50	·8488	1·475			

A convenient plan is to take the angles of the ground at contour pegs 100 feet apart and the base in feet. A table prepared for any given base and slope from the formula $B^2 K$ will give the contents for each length in "cubes" (100 cubic feet) per "line" (of 100 lineal feet), without the necessity for plotting the cross-sections.

SLOPES.—TABLE OF SUPERFICIES OF SLOPES corresponding with different Heights of Cutting or Embankment.
The Superficies is given in squares of 100 superficial feet per chain length.*

Height in feet.	Slopes to 1. ½.	1.	1½.	2.	Height in feet.	Slopes to 1. ½.	1.	1½.	2.
	Squares per Chain.					Squares per Chain.			
1	·74	·93	1·19	1·47	26	19·18	24·26	30·94	38·35
2	1·47	1·86	2·38	2·95	27	19·92	25·19	32·13	39·82
3	2·21	2·80	3·57	4·42	28	20·66	26·13	33·32	41·30
4	2·95	3·73	4·76	5·90	29	21·40	27·05	34·51	42·77
5	3·69	4·66	5·95	7 37	30	22·14	27·99	35·7	44·25
6	4·43	5·60	7·14	8·85	31	22·87	28·93	36·89	45·72
7	5·16	6·53	8·38	10·32	32	23·61	29·86	38·08	47·20
8	5·91	7·46	9·52	11·80	33	24·35	30·79	39·27	48·67
9	6·64	8·39	10·71	13·27	34	25·09	31·73	40·46	50·15
10	7·38	9·33	11·9	14·7	35	25·83	32·66	41·65	51·62
11	8·12	10·26	13 09	16·24	36	26·56	33·59	42·84	53·10
12	8·85	11·20	14·28	17·70	37	27·30	34·53	44·03	54·57
13	9·59	12·13	15·47	19·17	38	28·04	35·46	45·22	55·85
14	10·33	13·06	16·66	20 65	39	28·78	36·39	46·41	57·52
15	11·07	13·99	17·85	22·12	40	29·51	37·33	47·60	59·00
16	11·81	14·93	19·04	23·60	41	30·25	38·26	48·79	60·47
17	12·54	15·86	20·23	25 07	42	31·00	39·19	49·98	61·95
18	13·28	16·79	21·42	26·55	43	31·73	40·13	51·17	63·42
19	14·02	17·73	22·61	28·02	44	32·47	41·06	52·36	64·90
20	14·76	18·66	23·8	29·50	45	33·20	41·99	53·55	66·37
21	15·49	19·59	24·99	30·97	46	33 94	42·93	54·74	67·85
22	16·45	20·53	26·18	32·45	47	34·68	43·86	55·93	69·32
23	16·97	21·46	27·37	34·92	48	35·42	44·79	57·12	70·60
24	17·71	22·39	28·56	35·40	49	36·16	45·72	58·31	72·27
25	18·45	23·33	29·75	36·87	50	36·89	46·66	59·50	73·75

LENGTHS AND ANGLES OF SLOPES.

Slope.	Angle with horizon.	Length (height taken as 1·00).	Slope.	Angle with horizon.	Length (height being 1·00).
¼ to 1	75° 58′	1·0307	1½ to 1	33° 42′	1·802
½ to 1	63 26	1·118	1¾ to 1	29 44	2·016
¾ to 1	53 8	1·25	2 to 1	26 34	2·236
1 to 1	45 0	1·4142	3 to 1	18 26	3·162
1¼ to 1	38 40	1·6	4 to 1	14 2	4·124

* Gunter's chain. 66 feet.

Natural Slopes of Earths (*with Horizontal Line*).

Gravel, average	40°	Shingle	39°
Dry sand	38	Rubble	45
Sand	22	Clay, well drained	45
Vegetable earth	28	Ditto, wet ..	16
Compact earth	50		

Earthwork.

Proportion of Getters, Fillers, and Wheelers in different soils, Wheelers being calculated at 50 yards run.

	Getters.	Fillers.	Wheelers.
In loose earth, sand, &c.	1	1	1
,, Compact earth ..	1	2	2
,, Marl	1	2	2
,, Hard clay	1	1¼	1¼
,, Compact gravel ..	1	1	1
,, Rock, from	3	1	1

Weight of Earths, Rocks, &c., per cube yard.

Sand, about	30 cwt.		Sandstone, about	39 cwt.	
Gravel ,,	30	,,	Shale ,,	40	,,
Mud ,,	25	,,	Quartz ,,	41	,,
Marl ,,	26	,,	Granite ,,	42	,,
Clay ,,	31	,,	Trap ,,	42	,,
Chalk ,,	36	,,	Slate ,,	43	,,

Blasting.

L = Least line of resistance in feet.

X = Number of ounces of powder required to blast any rock when $L = 2$ feet.

P = Quantity of powder in ounces required.

Then $P = \frac{X L^3}{8}$,

Or when $X = 4$ ounces, $P = \frac{L^3}{2}$.

L should not exceed $\frac{1}{2}$ depth of hole.

Table of Charges when $X = 4$ ounces.

L.	Charge of powder.		L.	Charge of powder.	
feet.	lbs.	oz.	feet.	lbs	oz.
1	0	1	5	3	$14\frac{1}{2}$
2	0	4	6	6	12
3	0	$13\frac{1}{2}$	8	16	0
4	2	0			

In small blasts 1 lb. of powder will loosen about $4\frac{1}{2}$ tons.

In large blasts 1 lb. of powder will loosen about $2\frac{3}{4}$ tons.

One man can bore from 50 to 100 inches per day in granite, or 300 to 400 inches per day in limestone.

Blasting Agents. (Nobel.)

A = Ballistic power, weight for weight.
B = Do. do. bulk for bulk.
W = Relative weight; *h*, firing heat applied suddenly, Fahr.
G = Specific gravity; H, firing heat; material heated gradually.

Material.	A	B	W	G	*h*	H
Nitro-glycerine	100	1·00	1·00	1·60	—	—
Ammonia powder ..	·83	·80	·969	1·55	—	—
Dynamite	·72	·74	1·031	1·65	350°	446°
Lithofracteur	·50½	·53	1·06	1·70	—	—
Compressed gun-cotton	·71	·44	·625	1·00	360°	482°
Best blasting powder	·28	·17½	·625	1·00	500°	—

Ammonia powder consists of ..	Nitrate of ammonia	80	by weight.
	Charcoal	6½	
	Nitro-glycerine	10 to 20	
Dynamite ..	Porous silica	287	"
	Nitro-glycerine ..	75	
Lithofracteur..	Coal dust	2	"
	Nitrate of barium ..	5	
	Infusorial earth ..	23	
	Nitro-glycerine ..	70	

Contents of 1 inch of Bore-hole. (Andree.)

Diam. of hole (inches)	1	1¼	1½	1¾	2	2¼	2½	2¾	3
Gunpowder oz.	·419	·654	·942	1·283	1·675	2·120	2·618	3·166	3·769
Gun-cotton oz.	·419	·654	·942	1·283	1·675	2·120	2·618	3·166	3·769
Dynamite oz.	·670	1·046	1·507	2·053	2·680	3·392	4·189	5·066	6·030

Waterproof Composition for Submarine Blasting.

1, Tallow; 3, Rosin; 4, Gutta-percha; 12, Swedish pitch.

Dynamite cannot be ignited by a spark or blow, it is slow to catch fire. When ignited it burns fiercely, but leaves time for escape; if in large quantity, or confined, explosion may ensue. In winter dynamite freezes, and the cartridges require cautious thawing, which should be done in proper pans surrounded by hot water.

MINING. (Lefroy's 'Handbook of Field Service')

In the demolition of walls the line of less resistance L = half the thickness, and a is a coefficient depending on the structure.

The charge in lbs. $= a \times L^3$.

In a wall without counterforts, where the interval between the charge is 2 L, $a = 0\cdot15$.

In a wall with counterforts the charge to be placed in the centre of each counterfort at the junction with the wall, $a = 0\cdot2$.

Where the charge is placed under a foundation, having equal support on both sides, $a = 0\cdot4$.

If the foundation rests on woodwork, $a = 0\cdot5$ to $0\cdot6$.

If the charge is placed in the centre of a circular or polygonal mass of masonry, $a = 0\cdot1$.

A leather bag containing 50 or 60 lbs. of powder, hung or propped up, will demolish almost any gate or barrier.

For ordinary mines in average soil, the charge in lbs. $= \frac{L^3}{10}$.

BULK OF ROCK, EARTHWORK, &C., WHEN PLACED IN EMBANKMENT, ORIGINAL EXCAVATION BEING ASSUMED AT 1·00.

Rock, large blocks .. about	1·60
Medium, unselected	1·70
Metal	1·80
Chalk	1·70
Clay before subsidence	1·20
" after "	·92
Light Sandy soil	·89
Gravel	·92

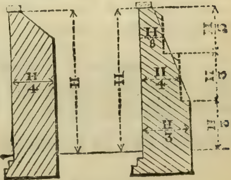
Retaining Walls.

E = Weight of earthwork per cube yard.
W = Weight of wall " "
H = Height of wall.
T = Thickness of wall at top.
T = H × Tabular No.

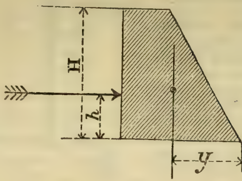
Batter of Wall.	E : W :: 4 : 5		E : W :: 1 : 1	
	Clay.	Sand.	Clay.	Sand.
1 in 4 ..	·083	·029	·115	·054
1 " 5 ..	·122	·065	·155	·092
1 " 6 ..	·149	·092	·183	·118
1 " 8 ..	184	·125	·218	·153
1 " 12 ..	·221	·160	·256	·189
Vertical ..	·300	·239	·336	·267

Sections of Perpendicular Retaining Walls sometimes adopted on Railways.

In large walls the offsets are more numerous, and follow the dotted line.



STABILITY OF WALLS, &c.



H = Height of the wall.
h = Height of centre of pressure from base.
= H ÷ 3 for still water.
B = Breadth of wall against which pressure acts.
W = Weight of the wall.
y = Distance of outer edge of the wall from the line of centre of gravity of the wall.
P = Pressure tending to overturn the wall.
m = Moment tending to overturn the wall.
= $\mathrm{P}h = 10 \cdot 4\ \mathrm{H}^3\,\mathrm{B}$ for water * in pounds.
M = Moment of stability of wall.
= W . y.

If M exceeds m, the wall will be stable provided that the materials on which it is constructed, or the foundations on which it rests, are sufficiently strong to resist crushing.

* H being the height of the surface of the water from the base.

RETAINING WALLS.

W = weight of a lineal foot of the wall in lbs.

w = weight of a cubic foot of the soil retained in lbs.

H = height of the wall in feet.

α = angle of repose of the soil = for dry sand, 36°; gravel or shingle, 39°; dry earth, 47°; moist earth, 54°.

β = angle of slope, if any, retained.

P = pressure on each lineal foot of the wall in lbs.

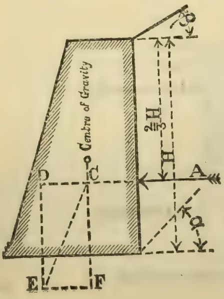
$$P = \frac{w\,H^2}{2} \times \frac{1 - \text{Sin.}\,\alpha}{1 + \text{Sin.}\,\alpha} \text{ when } \beta = 0;\quad P = \frac{w\,H^2.\,\text{Cos.}\,\alpha}{2}$$

when $\beta = \alpha$.

$$P = \text{Cos.}\,\beta\,\frac{\text{Cos.}\,\beta - \sqrt{\text{Cos}^2.\,\beta - \text{Cos}^2.\,\alpha}}{\text{Cos.}\,\beta + \sqrt{\text{Cos}^2.\,\beta - \text{Cos}^2.\,\alpha}} \times \frac{w.H^2}{2}$$ for any other slope.

To determine the stability of the wall, draw the horizontal line of the centre of pressure A D at ⅔ H from the top of the wall, cutting the vertical line, that passes through the centre of gravity of the wall, at C. Then, with any convenient scale, make C D = P; and C F = W; complete the parallelogram C D E F; draw the diagonal C E, and if, where it cuts the level of the base of the wall, it should fall outside the base, the equilibrium will be unstable.

In practice the diagonal should fall within the middle third of the base, as shown in the diagram.



Approximate Weight of a Cubic Foot in lbs.

Brickwork, 112–120; masonry, 115–150; dry sand, 90–110; wet sand, 150–170; shingle, 88; marl, 100–120; clay 120.

INEQUALITY OF PRESSURE ON FOUNDATIONS DUE TO LATERAL FORCE.

M = Moment of lateral force about axis of foundation.
p = Pressure per unit of surface from fixed load.
P = Greatest pressure per unit of surface from fixed load and lateral force together.
y = Distance from axis to edge of foundation.
I = Moment of inertia of plane of foundation about axis.

$$P = p + \frac{M\,y}{I}$$

FORM OF PIER TO SUSTAIN EQUAL PRESSURE PER UNIT OF SURFACE AT EVERY HORIZONTAL SECTION.

H = Height of a column of the material of which the pier is built, corresponding to the given pressure.
a = Area of top section of pier.
A = Area of horizontal section at depth h.
h = Depth measured from the top.

r = The number whose hyperbolic log. $= \frac{1}{H}$.

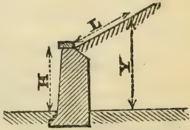
$A = a \times r^h$, or, in other words, $A = a\,N$, where N = that number whose common log. is equal to $\frac{\cdot 43429\,h}{H}$.

The contents of the pier $= H\,(A - a)$.

SURCHARGED WALLS.

In calculating the strength of surcharged walls, substitute Y for H.

Y being the perpendicular at the end of a line, L = H, measured along the slope to be retained.



Y = 1·71 H	in slopes of	1	to 1
= 1·55 H	,, ,,	$1\frac{1}{2}$	,, 1
= 1·45 H	,, ,,	2	,, 1
= 1·31 H	,, ,,	3	,, 1
= 1·24 H	,, ,,	4	,, 1

BRICKWORK.

1 rod of brickwork = 272 sup. ft., $1\frac{1}{2}$ brick thick.
,, ,, = $11\frac{1}{3}$ cub. yds. = 306 cub. ft.
,, ,, = 4350 bricks, average work.
,, ,, = 5370 bricks, laid dry.

36 bricks flat, or 52 on edge = 1 yard paving.

No. of bricks in 1 cubic yard = 384.

1 load of mortar .. .. .. = 1 cubic yard.
1 load of sand .. .. = 1 ,, ,,
1 bag of cement .. .. .. = 3 bushels.
1 sack of cement .. .. .. = 5 ,,

1 cubic yard brickwork requires about . .. .. $\left.\right\}$ $6\frac{1}{2}$ cubic feet sand. $2\frac{1}{2}$,, ,, lime.

330 stock bricks weigh 1 ton.
1000 ,, ,, $60\frac{3}{4}$ cwt.

1000 bricks closely stacked occupy about 55 cubic feet.

Bricks absorb about $\frac{1}{15}$th of their weight.

A bricklayer's hod measures 16″ × 9″ × 9 in.
,, ,, ,, contains 20 bricks.
,, ,, ,, ,, ,, $\frac{1}{2}$ a bushel of mortar, or $\frac{2}{3}$ cubic foot.

Table of Brick Dimensions.

The standard brick making, with joints, 9 in. × 4½ in. × 3 in.

No. of Bricks.	Dimension. ft	Dimension. in.	No of Bricks.	Dimension. ft.	Dimension. in.	No. of Bricks.	Dimension. ft.	Dimension. in.
½	0	4½	8½	6	4½	16½	12	4½
1	0	9	9	6	9	17	12	9
1½	1	1½	9½	7	1½	17½	13	1½
2	1	6	10	7	6	18	13	6
2½	1	10½	10½	7	10½	18½	13	10½
3	2	3	11	8	3	19	14	3
3½	2	7½	11½	8	7½	19½	14	7½
4	3	0	12	9	0	20	15	0
4½	3	4½	12½	9	4½	20½	15	4½
5	3	9	13	9	9	21	15	9
5½	4	1½	13½	10	1½	21½	16	1½
6	4	6	14	10	6	22	16	6
6½	4	10½	14½	10	10½	22½	16	10½
7	5	3	15	11	3	23	17	3
7½	5	7½	15½	11	7½	23½	17	7½
8	6	0	16	12	0	24	18	0

Brickwork.

Multipliers for different thicknesses of Wall from ½ brick to 3 bricks in thickness.						A = superficial area of Wall in square feet.
½.	1.	1½.	2.	2½.	3.	
·00123	·00246	·00368	·0049	·00613	·00737	× A = rods.
·01389	·02778	·04167	·05555	·06944	·08334	× A = cube yards.
·0053	·0106	·016	·0213	·0267	·032	× A = 1000 bricks.

Thickness of Brick Walls in Dwelling Houses.

Maximum Height of Wall in feet.	Maximum Length of Wall in feet.	Minimum Thickness of Wall in inches.							
		Basement.	1st floor.	2nd.	3rd.	4th.	5th.	6th.	Remainder.
100	U	30	26	26	21½	21½	17½	17½	13
"	80	26	26	21½	21½	17½	17½	—	13
"	45	21½	21½	17½	17½	17½	—	—	13
90	U	30	26	26	21½	17½	17½	—	13
"	70	26	21½	21½	17½	17½	—	—	13
"	45	21½	21½	17½	17½	—	—	—	13
80	U	26	21½	21½	17½	17½	—	—	13
"	60	21½	21½	17½	17½	—	—	—	13
"	45	21½	17½	17½	—	—	—	—	13
70	U	26	21½	21½	17½	—	—	—	13
"	55	21½	17½	17½	—	—	—	—	13
"	40	17½	17½	—	—	—	—	—	13
60	U	21½	17½	17½	—	—	—	—	13
"	50	17½	17½	—	—	—	—	—	13
"	30	17½	—	—	—	—	—	—	13
50	U	21½	17½	—	—	—	—	—	13

Maximum Height of Wall in feet.	Maximum Length of Wall in feet.	Basement.	Between Basement and next below top.	Next below top.	Top story.
50	45	17½	13	13	8½
"	30	13	13	13	8½
40	U	17½	13	13	8½
"	35	13	13	8½	8½
30	U	13	13	13	8½
"	35	13	13	8½	8½
25	U	13	13	13	8½
"	30	8½	8½	8½	8½

The letter U means that the length of the wall is unlimited. The thickness of the wall is to be increased to $\frac{1}{16}$th of the height of the story in case the proportion determined above falls short of this thickness. Footings to be double the thickness of the basement wall, diminishing in regular offsets, of which the base = ½ the height.

Thickness of Brick Walls for Warehouses.

L = Maximum length of wall in feet.
T = Thickness of wall at base in inches.
The letter U means that L is unlimited.

	Maximum Height of Wall in feet.								
	100.	90.	80.	70.	60.	50.	40.	30.	25.
When L =	U	U	U	U	U	U	U	U	U
T =	34	34	30	26	26	26	21½	17½	13
When L =	70	70	60	45	50	70	60		
T =	30	30	26	21½	21½	21½	17½		
When L =	55	60	45	30	35	40	30	45	
T =	26	26	21½	17½	17½	17½	13	13	

In walls not more than 30 feet high, top story may be 8½ inches thick.

Thickness of higher walls at top and 16 feet below = 13 inches.

From 16 feet below top to base the wall not to be less than the space contained in the two straight lines drawn from each side of the walls at the base to each side of the wall 16 feet below the top.

The thickness to be in no case less than $\frac{1}{14}$th of the height of the story. Footings to be double the width of the base, diminishing in regular offsets ½ the width of their height.

Plastering.

	1 in. thick.	¾ in. thick.	½ in. thick.
1 bushel of cement or 1·28 cubic foot will cover ..	$1\frac{1}{7}$ s. yd.	$1\frac{1}{2}$ s. yd.	$2\frac{1}{4}$ s. yd.
1 cement and 1 sand	$2\frac{1}{4}$,,	3 ,,	$4\frac{1}{2}$,,
1 cement and 2 sand	$3\frac{1}{3}$,,	$4\frac{1}{2}$,,	$6\frac{3}{4}$,,

1 cube yard of lime, 2 yards of sand, and 3 bushels of hair will cover — 75 yards sup. render and set, on brick, or 70 yards on lath.

Mortar, Cement, &c.

Mortar.—1 of lime to 2 to 3 of sharp river sand.

Or 1 of lime to 2 sand and 1 blacksmith's ashes, or coarsely-ground coke.

Coarse Mortar.—1 of lime to 4 of coarse gravelly sand.

Concrete.—1 of lime to 4 of gravel and 2 of sand.

Hydraulic Mortar.—1 of blue lias lime to $2\frac{1}{2}$ of burnt clay, ground together.

Or 1 of blue lias lime to 6 of sharp sand, 1 of puzzolana and 1 of calcined ironstone.

Beton.—1 of hydraulic mortar to $1\frac{1}{2}$ of angular stones.

Cement.—1 of sand to 1 of cement.—If great tenacity is required, the cement should be used without sand.

Waterproof Mastic Cement.—1 of red-lead to 4 of ground lime and 5 of sharp sand mixed with boiled oil.

Or 1 of red-lead to 5 of whiting and 10 of sharp sand mixed with boiled oil.

Portland Cement is composed of clayey mud and chalk ground together, and afterwards calcined at a high temperature—after calcining it is ground to a fine powder.

Portland Cement.

Conclusions derived from Mr. Grant's Experiments.

1. Portland cement improves by age, if kept from moisture.

2. The longer it is in setting the stronger it will be.

3. At the end of a year, 1 of cement to 1 sand is about $\frac{3}{4}$ths the strength of neat cement; 1 to 2 about $\frac{1}{2}$ strength; 1 to 3 about $\frac{1}{3}$rd; 1 to 4, $\frac{1}{4}$th; 1 to 5 about $\frac{1}{6}$th.

4. The cleaner and sharper the sand the greater the strength.

5. Strong cement is heavy; blue grey, slow-setting. Quick-setting cement has generally too much clay in its composition—is brownish and weak.

6. The less water used in mixing up the cement the better.

7. Bricks, stones, &c., used with cement should be well soaked.

8. Cement setting under *still* water will be stronger than if kept dry.

9. Blocks of brickwork or concrete should be kept in water until required for use.

10. Salt-water is as good as fresh for mixing cement.

11. Bricks of neat Portland cement are equal to Blue bricks, Bramley-Fall stone, or Yorkshire landings (in a few months).

12. Bricks of 1 cement to 4 or 5 of sand are equal to picked stock bricks.

PORTLAND CEMENT—*continued.*

13. When concrete is used, a current, either by pumping or otherwise, will carry away the cement and leave only the clean ballast.

14. Roman cement is only about $\frac{1}{3}$rd of the strength of Portland, and is ill adapted for being mixed with sand.

CONCRETE WALLS.

Concrete walls for houses are built of 1 of cement to 6 or 7 of broken stone, mill-cinders, burnt ballast, shingle, gravel, or slag. The substance mixed with the cement must be thoroughly free from loam, mud, fine sand, clay, or dirt of any kind. Mixture to prevent the cement from adhering to the plates, 1 lb. of yellow soap, cut in shreds, boiled and stirred until it is of the consistency of paint—to be applied freely with a brush to all parts before the concrete is placed in contact with them.

CRUSHING WEIGHT OF PORTLAND CEMENT in lbs. per square inch. (Grant.)

	No. of Months made.		
	3.	6.	9.
Neat Portland Cement	3795	5388	5984
1 Cement to 1 Sand	2491	3478	4561
1 „ 2 „	2004	2752	3647
1 „ 3 „	1436	2156	2393
1 „ 4 „	1331	1797	2209
1 „ 5 „	959	1540	1678

About $\frac{5}{8}$ of the crushing weights produced the first crack.—Min. Inst. Civ. Eng.,' vol. xxv.

Portland Cement Concrete.
(Sandeman, 'Trans. Inst. Civ. Eng.,' vol. liv.)

Proportions to 1 of Cement.			Volume of Mortar per cent. of Concrete.	Strength compared with Mortar, 1 Sand to 1 Cement.	
Sand.	Aggregates.	Total.		Tensile.	Compressive.
1	3·16	4·16	42·4	1·	1·
2	2·16	4·16	61·73	·655	·655
2	4·74	6·74	42·4	·655	·655
3	3·74	6·74	55·4	·458	·438
3	6·32	9·32	42·4	·458	·438
4	5·32	9·32	52·19	·316	·315

Volume of Interstices in Concrete.

	Per cent. of Total.
Welsh limestone broken in a stone crusher into flat oblong pieces, which, when gauged the narrowest way, would pass through 3″ ring	51
Gravel free from sand gauged through $2\frac{1}{2}$″ ring	34
Welsh limestone and gravel as above, in equal proportions	34
Limestone (masons' chips) varying in size from small to pieces gauged by 4″ ring ..	48
Red sandstone, hand broken, gauged from 4″ to 8″ ring	50
Ditto, from sand to pieces gauged by 4″ ring	34
Ditto, two previous materials mixed in equal proportions	36
Reduction of bulk of dry cement mixed with water	$10\frac{1}{2}$
Ditto of sand	20
Ditto of sand and cement in equal proportions	$19\frac{1}{4}$

NOTES ON LIME

CLASSIFICATION OF LIMESTONES. (Vicat.)

1 FAT LIME.—Pure lime which does not set in water 2. POOR LIME.—Mixed with sand, which does not alter its condition. 3. SLIGHTLY HYDRAULIC LIME, containing 8 to 12 per cent. of silica, aluminia, magnesia, iron, and manganese, sets slowly in water 4 HYDRAULIC LIME, containing 12 to 20 per cent of the above ingredients, sets in water in six or eight days. 5 EMINENTLY HYDRAULIC LIME, containing 20 to 30 per cent of the above, sets in two to four days. 6 HYDRAULIC CEMENT, containing 30 to 50 per cent. of argil, sets in a few minutes, and attains the hardness of stone in a month "Puzzolana" and "Trass," volcanic products, if mixed with pure lime, make hydraulic mortars.

ROUGH INDICATIONS OF LIMESTONES.

They dissolve wholly or partly in weak acids, with brisk effervescence. They are nearly insoluble in water They can be scratched with an iron point

ROUGH ANALYSIS OF LIMESTONE (Rourkee Treatise).

1. Pound the sample, and pass it through a fine sieve. 2. Put 150 grains into a tumbler, and pour gradually on it diluted hydrochloric acid, stirring and adding the acid until effervescence ceases. 3. Filter through blotting paper, and then wash by pouring at least a quart of water through it. 4. Carefully collect the remainder, dry, and weigh it; its weight deducted from 150 grains will give the weight of carbonate of lime. 5. Wash the remainder repeatedly with decantation to remove the lighter particles of clay, then dry and weigh the sediment, which may be assumed to be sand. 112 grs. carbonate of lime, 9 of clay, and 29 of sand will be a fair proportion for general purposes.

Notes on Lime—*continued.*

ROUGH TESTS OF HYDRAULIC LIMESTONES OR CEMENT (Pasley).

Colour bluish grey, brown, or some darkish colour.
Taste of clay when touched by the tongue.
Smell of clay after wetting.

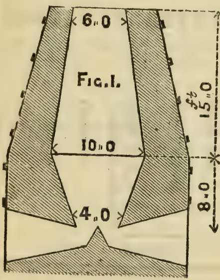
1. Break into fragments about $1\frac{1}{2}$ inches thick, heat gradually in a common fire, and then keep to a full red heat for about three hours. If it has been overburnt, it will be of a darker colour than before when taken out of the fire. If properly calcined, no effervescence will take place when it is placed in a glass of dilute hydrochloric acid.

2 Having obtained a piece properly calcined, pound it to an impalpable powder, leaving no grit. Mix thoroughly under a spatula or kitchen knife with about $\frac{1}{3}$ of its bulk of water, then knead into a ball, which should soon become warm.

3. When the ball has begun to cool, place it under water, when it should not only continue hard, but go on hardening. Its hydraulicity will be determined by the time it requires to harden and the hardness it attains.

LIME BURNING. SECTION OF KILNS.

Fig 1 Will burn 240 cubic feet of lime per day.
Fig. 2. 150.



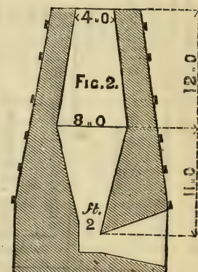


TABLE SHOWING THE QUANTITY OF MORTAR PRODUCED FROM ONE IMPERIAL BUSHEL OF VARIOUS LIMES AND CEMENTS. (*By experiment.* Hurst.)

	Description.	Lime or cement. Weight in lbs. per bushel.	Lime or cement. No. of bushls.	Sand. No. of bushls.	Water. No. of galls.	Quantity of mortar in cubic feet.	
In Stone.	Stone Lime (Plymouth)	70	1	3	12	3½	6 gallons of water are required to slake, and 6 galls. to mix each bushl.
In Stone.	,, ,,	70	1	3	12	4	
In Stone.	,, ,,	70	1	3	12	5	
In Stone.	Lias (Keynsham)	80	1	3	9½	$3\frac{1}{12}$	3 gallons of water are required to slake each bushel.
In Stone.	,, ,,	80	1	3	10	$3\frac{2}{3}$	
In Stone.	,, ,,	80	1	4	12	$4\frac{1}{3}$	
	,, (Lyme Regis)	70	1	2	8½	2¾	2 gallons of water are required to slake each bhl.
	,, ,,	70	1	3	8½	3¼	
Ground.	,, (Keynsham)	63	1	2	4¾	2½	
Ground.	,, ,,	63	1	3	5½	$2\frac{5}{6}$	
Ground.	,, ,,	63	1	3	6½	$3\frac{1}{8}$	
Ground.	,, (Lyme Regis)	74	1	2	6	2¾	
	Cement, Roman	72	1	None.	6½	$1\frac{1}{8}$	
	,, ,,	72	1	1	6¼	1¾	
	,, Portland	99	1	1	3¾	1¾	
	,, ,,	99	1	1	3½	1¾	
	,, ,,	99	1	1	3¼	1¾	
	,, ,,	99	1	1½	$4\frac{1}{8}$	$2\frac{1}{12}$	
	,, ,,	99	1	2	5¼	$2\frac{7}{12}$	
	,, ,,	99	1	3	6¾	3½	

Notes on Timber.

GENERAL CHARACTER.

In the same class of timber the slower the growth or the narrower the annular rings the better. In the same class the heavier the better. The cellular tissue (when visible) in the medullary rays should be hard and compact. The fibrous tissues should adhere firmly together, and should show no woolliness at a freshly-cut surface; loose fibres should not clog the teeth of the saw. If the wood has colour, deepness of colour indicates strength and durability. The freshly-cut surface of wood should be firm, shining, and somewhat translucent. A dull, chalky appearance is a sign of bad timber. In resinous timber, those with least resin in their pores are strongest and most durable. In non-resinous timber, those with least sap or gum are best.

SEASONING TIMBER.

Timber should be felled in winter when the sap is down. Timber should be seasoned from three to five years before it is fit for use. It should be removed from the forest as soon as possible, and stacked where it will not be exposed to the sun, the butt end downwards; the pores of the butt exposed to the action of the air. Squared timber is less apt to split than round timber; split timber less than sawn timber. Seasoning may be effected more rapidly by soaking in water, or boiling. These processes, however, weaken the timber. Soaking in water should continue for about a fortnight; the timber should be freshly

NOTES ON TIMBER—*continued.*

cut when soaked. Boiling in steam or water should last from four to six hours. The wood should be gradually dried afterwards.

DESICCATING PROCESS.

The timber is placed in a chamber through which a current of hot air is passed.

Temperature of air 100° Fahr. for hard wood in logs, 120° for pine; up to 180° or 200° Fahr. for thin planks. Mahogany 280° to 300°.

Velocity of current of air 100 feet per second.

Sufficient air should be forced into the chamber to displace all the air in three minutes; or for every 3 cubic feet of air in the chamber, 1 cubic foot of air per minute should be supplied.

Duration of process, one week for each inch of thickness of the timber.

IMPREGNATION OF TIMBER.

Relative absorbing power of timber, Memel being assumed = 1·00; elm = 1·35; yellow pine = 1·15; beech = ·4; English oak = ·34.

CREOSOTING. (Bethell's.)

The sleepers are either dried in the open air for $1\frac{1}{2}$ year, or oven-dried at temperature varying from 212° to 250° Fahr., either until they cease to emit steam or for twenty-four hours. They are then placed in the impregnating chamber, and subjected to a vacuum of 3 to 5 lbs. per square inch, from $\frac{1}{2}$ to $\frac{3}{4}$ of an hour. The creosote is then forced in at a pressure varying from 100 to 150 lbs. per square inch, according to the length

IMPREGNATION OF TIMBER—*continued.*

of timber, for a period varying from $\frac{3}{4}$ of an hour to $2\frac{1}{2}$ hours.

8 lbs. or ·8 gallon should be the quantity absorbed.

10 lbs. or 1 gallon for marine works.

Oak will not absorb more than 6 lbs.

Red pine will absorb 15 or 16 lbs.

Mr. Bethell prefers to use for creosoting timber with the outer layers intact, because the outer wood absorbs the creosote more readily, and sap-wood fully impregnated **is** more durable than heart-wood unimpregnated.

Creosoting about doubles the life of sleepers if *properly performed*, and is uniformly satisfactory.

IMPREGNATION WITH METALLIC SALTS.

The result of impregnation with metallic salts has not in all cases been satisfactory.

BURNETT's Chloride of Zinc, with 25 to 40 per cent. of metallic zinc (3 parts of hydrochloric acid to 1 of zinc). The mixture is diluted with from 30 to 60 parts of water, and applied under pressure of 100 to 120 lbs. per square inch for fifteen minutes.

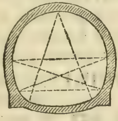
KYAN's Chloride of Mercury, diluted with 150 parts of water, applied cold without pressure.

MARGERY's Sulphate of Copper, diluted with 40 to 50 parts of water, applied with pressure varying from 15 to 30 lbs. per square inch, for six or eight hours.

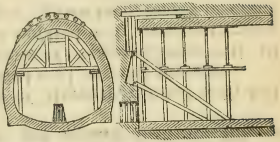
PAINE's Sulphate of Iron and Sulphate of Barium. This appears to give rise to a slow decomposition and destruction of the fibres of the wood.

TUNNELS. (See also "Ventilation of Tunnels.")

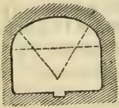
HOOSAC TUNNEL. LINED SECTION.



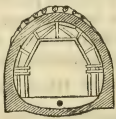
SALTWOOD TUNNEL. LOWER GREENSAND.



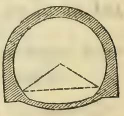
HOOSAC TUNNEL. UNLINED SECTION.



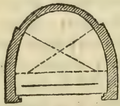
BUCKHORN WESTON, IN KIMMERIDGE CLAY.



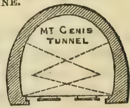
HAUENSTEIN TUNNEL, IN LIMESTONE, SANDSTONE, AND SHALE.

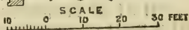


LYDGATE TUNNEL, IN SHALE.



INDIAN STATE RAILWAY. SINGLE LINE.





MT. CENIS TUNNEL.
Length, 7·6 miles.

RATE OF PROGRESS OF HEADING IN YARDS PER YEAR.

	Yards.
By hand in carbonaceous schist	199
" " calcareous schist..	270
By machine in calcareous schist ..	415 to 973
" average of last 4 years ..	844
" in carbonaceous schist ..	510
" in quartz	232
" in magnesian limestone ..	752

TUNNELS,
From actual Practice in Brickwork.

Purpose.	Formation of Strata.	Extreme height.		Extreme width.		Thickness of lining at Crown.	
		ft.	in.	ft.	in.	ft.	in.
Canal	Various	16	2	17	0	1	2
"	London Clay	21	6	20	0	1	6
Thames Tunnel	" "	22	3	37	6	2	6
Railway, N. gauge	Chalk	26	6	27	0	1	6
" "	Various	27	6	27	0	1	10½
" "	Shale	30	0	30	0	1	10½
" "	Lower Green Sand	30	6	30	0	2	3
" B. "	Freestone	36	0	36	0	2	3
Canal	Chalk and Fuller's Earth	39	0	35	6	1	2

TABLE OF WELLS OR BARREL-DRAINS.
Quantities in One Lineal Yard.

Diam. in feet.	Contents in gallons.	½ Brick thick.			1 Brick thick.		
		Cube yards. Brickwork.	No. of bricks. Dry.	No. of bricks. In mortar.	Cube yards. Brickwork.	No. of bricks. Dry.	No. of bricks. Mortar.
1½	33	·25	114	93	·59	270	222
2	58	·31	144	123	·72	336	276
3	131	·44	204	171	·98	462	378
4	235	57	267	219	1·24	582	477
5	368	·7	330	270	1·5	702	576
6	530	·83	390	321	1·77	828	678
7	723	·96	450	369	2·03	948	780
8	942	1·09	510	420	2·28	1074	876
9	1193	1·22	573	468	2·55	1194	978
10	1472	1·36	636	522	2·81	1314	1080

Table of Culverts for Railways.

	Diameter.		Thickness of Arch.		Thickness of Invert.		Thickness of Sides.		Clear height inside.		Cube yds. in 1 lineal yd. of culvert.
	ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.	
Brickwork..	1	6	0	9	Barrel.						0·60
	2	0	0	9	Barrel.						0·75
	3	0	0	9	0	9	1	2	3	3	1·60
	4	0	1	2	0	9	1	6	4	6	3·30
	5	0	1	2	0	9	1	10	5	6	4·70
	6	0	1	6	0	9	2	3	6	6	6·10
Rubble masonry with hammer-dressed arches ..	flat top 1	6	0	6	1	0	1	6	2	6	1·50
	flat top 2	0	0	9	1	0	2	0	3	0	2·00
	3	0	1	0	0	9	2	6	3	3	4·00
	5	0	1	0	1	0	3	0	5	6	6·70
	6	0	1	4	1	0	3	6	6	6	7·60

Table of the Thickness required for the Crowns of Arches. (Hurst.)

Radius of Curvature.	Stone Arches.	Brick Arches.	Radius of Curvature.	Stone Arches.	Brick Arches.	Radius of Curvature.	Stone Arches.	Brick Arches.
feet.	feet.	feet.	feet.	feet.	feet.	feet.	feet.	feet.
2	·42	·56	14	1·12	1·50	60	2·33	3·10
2½	·47	·63	15	1·16	1·55	65	2·42	3·22
3	·52	·69	16	1·20	1·60	70	2·51	3·35
3½	·56	·75	17	1·24	1·65	75	2·60	3·46
4	·60	·80	18	1·27	1·70	80	2·68	3·58
4½	·64	·85	19	1·32	1·74	85	2·77	3·69
5	·67	·90	20	1·34	1·79	90	2·85	3·80
5½	·71	·94	22	1·41	1·88	95	2·92	3·90
6	·74	·98	24	1·47	1·96	100	3·00	4·00
7	·80	1·06	25	1·50	2·00	110	3·15	4·20
8	·85	1·13	30	1·64	2·19	120	3·29	4·38
9	·90	1·20	35	1·78	2·37	130	3·42	4·56
10	·95	1·26	40	1·90	2·53	140	3·35	4·73
11	1·00	1·33	45	2·01	2·68	150	3·67	4·90
12	1·04	1·38	50	2·12	2·83	160	3·80	5·06
13	1·08	1·44	55	2·22	2·97	170	4·18	5·58

Approximate Rules for the Thickness of Arches and Abutments. (Hurst.)

D = Depth or thickness of crown in feet.
H = Height of abutment to springing in feet.
R = Radius of arch at crown in feet.
T = Thickness of abutment in feet.
W = Weight of 1 foot in length of half arch in cwts.
n = Constant.

$$D = n\sqrt{R}$$

Single arches :—		Series of arches :—	
Block Stone	$n = \cdot 3$	Block Stone	$n = \cdot 35$
Brick ..	$n = \cdot 4$	Brick ..	$n = \cdot 45$
Rubble ..	$n = \cdot 45$	Rubble ..	$n = \cdot 5$

$$T = \sqrt{\tfrac{1}{5}R^2 + \tfrac{3}{5}R^{\frac{3}{2}} + \left(\frac{W}{H}\right)^2} - \frac{W}{H}.$$

This formula gives the thickness T of abutment without wing-walls or counterforts just sufficient to balance the thrust of the half arch, the depth at the crown being equal to $\cdot 4\sqrt{R}$, and the material in the arch and abutment being the same.

A considerable margin of safety must be allowed on the dimensions thus given.

Rule sometimes used for Railway Bridges.

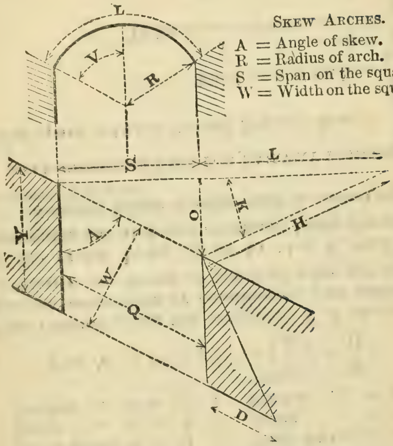
For spans between 25 and 70 feet—Rise $= \frac{S}{5}$

Thickness of arch $= \frac{S}{18}$

Thickness of abutments $\frac{S}{5}$ to $\frac{S}{4}$

Thickness of pier $\frac{S}{6}$ to $\frac{S}{7}$

Batter (if any) 1 inch to the foot.



Skew Arches.

A = Angle of skew.
R = Radius of arch.
S = Span on the square.
W = Width on the square.

Q = Span on the skew = S cosecant A
Y = Length of impost = W cosecant A
O = Obliquity of arch = S cotan. A.
L = Length of arc = ·0349 R V.
= In semicircular arches = 1·5708 S.

$$\text{Sine V} = \frac{\text{S}}{2\ \text{R}}.$$

H = Length of heading spiral = L secant K.

$$\text{Tan. K} = \frac{\text{S cotan. A}}{\text{L}}.$$

D = Divergence of courses = Y sine K.

STRENGTH OF COLUMNS.

LONG COLUMNS. (Hodgkinson.)

W = Breaking weight in tons.
L = Length of column in feet.
D = External diameter of column in inches.
d = Internal diameter in inches.

Nature of Column.	Both ends rounded when L exceeds 15 D.	Both ends flat when L exceeds 30 D.
Solid cylinders of cast iron.. ..	$W = 14 \cdot 9 \frac{D^{3 \cdot 76}}{L^{1 \cdot 7}}$	$W = 44 \cdot 16 \frac{D^{3 \cdot 55}}{L^{1 \cdot 7}}$
Hollow cylinders of cast iron.. ..	$W = 13 \frac{D^{3 \cdot 76} - d^{3 \cdot 76}}{L^{1 \cdot 7}}$	$W = 44 \cdot 34 \frac{D^{3 \cdot 55} - d^{3 \cdot 55}}{L^{1 \cdot 7}}$
Solid square of Dantzic oak (dry)	.. ..	$W = 10 \cdot 95 \frac{D^4}{L^2}$
Solid square of red deal (dry) ..	.. ..	$W = 7 \cdot 81 \frac{D^4}{L^2}$

TABLE OF 3·6 AND 1·7 POWER.

No.	3·6 power.	No.	3·6 power.	No.	3·6 power.
3	52	10	3982	17	26892
4	147	11	5611	18	33035
5	328	12	7674	19	40133
6	632	13	10233	20	48273
7	1102	14	13367	21	57543
8	1783	15	17136	22	68033
9	2723	16	21619	24	93058

No.	1·7 power.	No.	1·7 power.	No.	1·7 power.	No.	1·7 power.
5	15	15	100	25	238	40	529
8	34	18	136	28	288	50	773
10	50	20	163	30	325		
12	68	22	191	35	421		

STRENGTH OF SHORT COLUMNS,

In which L is less than 30 D.

w = Breaking weight of short columns.
W = Breaking weight of long columns as found above.
C = Crushing force of material of which the column is formed × Sectional area of column.

$$w = \frac{W\,C}{W + \frac{3}{4}C}.$$

RELATIVE STRENGTH OF MATERIALS IN LONG COLUMNS.

Cast iron being assumed as	= 1000
Wrought iron	= 1745
Cast steel	= 2518
Oak	= 109
Red deal	= $78\frac{1}{2}$

RELATIVE STRENGTH OF ROUND AND FLAT ENDS IN LONG COLUMNS.

Both ends rounded, 1 strength	= 1
One end flat and firmly fixed, 1 strength	= 2
Both ends flat and firmly fixed	= 3

RELATIVE STRENGTH OF SECTION IN LONG SOLID COLUMNS.

Cylindrical	100
Triangular	110
Square	93

Cast-iron Columns. (Hurst.) $\frac{1}{10}$th of Breaking Weight in tons of *Solid* Columns, ends flat and fixed.

Diam. in inches.	Length of Column in feet.								
	6.	8.	10.	12.	14.	16.	18.	20.	25.
1½	·82	·50	·34	·25	·19	·15	·13	·11	·07
1¾	1·43	·87	·60	·44	·34	·27	·22	·18	·13
2	2·31	1·41	·97	·71	·55	·44	·36	·30	·20
2¼	3·52	2·16	1·48	1·08	·83	·67	·54	·46	·31
2½	5·15	3·16	2·16	1·58	1·22	·97	·80	·66	·56
2¾	7·26	4·45	3·05	2·23	1·72	1·37	1·12	·94	·64
3	9·93	6·09	4·17	3·06	2·35	1·87	1·53	1·28	·88
3½	17·29	10·60	7·26	5·32	4·10	3·26	2·67	2·23	1·53
4	27·96	17·15	11·73	8·61	6·62	5·28	4·32	3·61	2·47
4½	42·73	26·20	17·93	13·15	10·12	8·07	6·60	5·52	3·78
5	62·44	38·29	26·20	19·22	14·79	11·79	9·65	8·06	5·52
5½	88·00	53·97	36·93	27·09	20·84	16·61	13·60	11·37	7·78
6	120·4	73·82	50·51	37·05	28·51	22·72	18·60	15·55	10·64
6½	160·6	98·47	67·38	49·43	38·03	30·31	24·81	20·74	14·19
7	209·7	128·6	87·98	64·53	49·66	39·57	32·39	27·08	18·53
7½	268·8	164·8	112·8	82·73	63·66	50·73	41·53	34·72	23·76
8	339·1	207·9	142·3	104·4	80·31	64·00	52·39	43·80	29·97
8½	421·8	258·6	177·0	129·8	99·90	79·61	65·16	54·48	37·28
9	518·2	317·7	217·4	159·5	122·7	97·80	80·05	66·92	45·80
9½	629·5	386·0	264·2	193·8	149·1	118·8	97·25	81·70	55·64
10	757·2	464·3	317·7	233·1	179·3	142·9	117·0	97·79	66·92
10½	902·6	553·5	378·7	277·8	213·8	170·3	139·4	116·6	79·77
11	1067·1	654·4	447·8	328·5	252·7	201·4	164·9	137·8	94·31
11½	1252·3	767·9	525·5	385·4	296·6	236·4	193·5	161·7	110·7
12	1459·6	895·1	612·5	449·3	345·7	275·5	225·5	188·5	129·0

The correction for Short Columns should be applied where the length is less than 30 D.

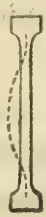
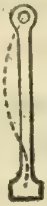
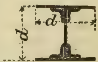
$$\text{Strength in tons of Short Columns} = \frac{S\,C}{10\,S + \frac{3}{4}C},$$

S being the strength for Long Columns given in the above Table, and C = 49 times the sectional area of the metal in inches.

Hollow Columns.

The strength nearly equals the difference between that of two Solid Columns the diameters of which are equal to the External and Internal diameters of the hollow one.

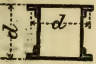
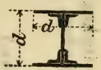
STRENGTH OF STRUTS AND PILLARS.

Authority.	A  (A) Ends flat or fixed.	B  (B) One end fixed, the other end rounded or hinged.	C  (C) Both ends rounded or hinged.	
Gordon $P=$	$\frac{F}{1+kH^2}$		$\frac{\cdot 3F}{1+kH^2}$	Wt. Iron. Cast. Timber. $F=$ 16 35 $k=$ ·00033* ·0025*
Rankine $P=$	$\frac{F}{1+kh^2}$	$\frac{F}{1+1{\cdot}78\,kh^2}$	$\frac{F}{1+4kh^2}$	$F=$ 16 35 3·2 $k=$ ·000028 ·00031 ·00033
Shaler Smith } $P=$	$\frac{17{\cdot}2}{1+{\cdot}00017H^2}$	$\frac{17{\cdot}2}{1+{\cdot}00044H^2}$	$\frac{16{\cdot}7}{1+{\cdot}00053H^2}$	
„ $P=$	$\frac{19{\cdot}}{1+{\cdot}00022H^2}$	$\frac{17{\cdot}9}{1+{\cdot}00044H^2}$	$\frac{16{\cdot}3}{1+{\cdot}00067H^2}$	
„ $P=$	$\frac{16{\cdot}3}{1+{\cdot}00027H^2}$	$\frac{16{\cdot}3}{1+{\cdot}00044H^2}$	$\frac{16{\cdot}3}{1+{\cdot}00057H^2}$	
„ $P=$	$\frac{16{\cdot}3}{1+{\cdot}00037H^2}$	$\frac{16{\cdot}3}{1+{\cdot}00067H^2}$	$\frac{16{\cdot}3}{1+{\cdot}00083H^2}$	

P = Crippling strain in tons per square inch of cross section.
F = Ultimate crushing strain of a short length of material, tons per square inch.
k = Coefficient.
L = Length of column.
d = Diameter of column in direction of greatest flexure.
r = Radius of gyration in „ „
$H = \frac{L}{d}$; $h = \frac{L}{r}$.

* For circular section; k = ·0005 and ·0037 for rectangular section; and ·0001 and ·0075 for I section in wrought and cast iron respectively.

ULTIMATE CRIPPLING STRAIN OF COLUMNS IN TONS PER SQUARE INCH OF SECTION.

$H = \frac{\text{Length}}{\text{Diameter}}$.													$H = \frac{\text{Length}}{\text{Diameter}}$.
	A	B	C	A	B	C	A	B	C	A	B	C	
15	16·55	15·99	15·09	18·07	16·23	14·21	15·37	14·81	14·44	15·04	14·17	13·69	15
20	16·08	15·17	13·94	17·42	15·16	12·90	14·72	13·84	13·26	14·19	12·86	12·22	20
25	15·55	14·22	12·70	16·66	13·99	11·53	13·96	12·75	12·00	13·23	11·50	10·71	25
30	14·88	13·22	11·45	15·81	12·75	10·21	13·14	11·64	10·76	12·22	10·18	9·31	30
35	14·20	12·20	10·26	14·96	11·56	8·99	12·28	10·55	9·58	11·21	8·97	8·06	35
40	13·48	11·21	9·16	14·00	10·44	7·90	11·42	9·52	8·51	10·23	7·88	6·98	40
45	12·75	10·26	8·17	13·08	9·40	6·95	10·56	8·58	7·11	9·31	6·93	6·06	45
50	12·02	9·38	7·29	12·19	8·45	6·12	9·78	7·72	6·71	8·46	6·11	5·28	50
55	11·86	8·56	6·51	11·34	7·62	5·42	9·02	6·95	5·97	7·68	5·40	4·63	55
60	10·62	7·81	5·83	10·54	6·85	4·81	8·30	6·27	5·33	6·98	4·79	4·07	60

Note.—The table above has been calculated from Mr. Shaler Smith's formulæ, a modified form of which is given in the preceding page. Mr. Shaler Smith in calculating the safe loads uses the "sliding" factor of safety 4 + 0·05 H, which has been introduced to allow for imperfections of "built up" pillars.

Pile Driving.

D = Set of pile by the last blow in inches.
H = Height the ram has fallen in inches.
L = Safe load for the pile in cwts.

$$L = \frac{W\,H}{8\,D} \text{ approximately. (Sanders.)}$$

W = Weight of ram in cwts.
W = 10 to 14 cwt. in ordinary pile engines.

Rankine's rule for L is 1000 lbs. per square inch of section when the pile is driven home to firm ground, and 200 when it is not.

ANOTHER RULE (Rankine)

W = Weight of ram
h = Height of fall.
d = Depth driven by last blow.
s = Sectional area of pile.
l = Length of pile.
E = Modulus of elasticity.
L = Greatest dead load the pile will bear without sinking lower.

$$L = \sqrt{\left(\frac{4\,E\,s\,W\,h}{l} + \frac{4\,E^2\,s^2 d^2}{l^2}\right)} - \frac{2\,E\,s\,d}{l}.$$

DUTCH RULE.

L = Load the pile is to bear.
W = Weight of ram; h = fall of ditto.
M = Weight of pile; k = coefficient of safety.
k = 10 for ordinary = 6 for steam pile drivers.
e = Average penetration of the last blows.

$$L = \frac{W^2\,h}{k\,e(W + M)}.$$

Limit of driving in sand = 15 feet.

Weisbach's Rule.

W = Weight of the ram.
h = Height of fall.
P = Weight of the pile.
d = Depth driven by the last blow.
L = Greatest load the pile will bear.

$$= \frac{W^2 h}{d(W + P)}.$$

In this, as well as in Rankine's rule, the safe load, in ordinary cases, may be assumed at $\frac{1}{5}$ of the greatest load; where there is much vibration, and variation of load, $\frac{1}{7}$ to $\frac{1}{8}$ may be adopted; where there is no vibration, or variation of load, $\frac{1}{3}$.

In the case of Rankine's rule, Mr. Morrison suggests the substitution of $l_1 + 2 l_2$ for l; where l_1 is the length of pile buried and l_2 the length above ground.

Morrison's Rule.

Find by experiment the effect of two different falls of the ram when the pile is nearly driven home. Then if

H & h = the height of each fall respectively.
D & d = the depth the pile is driven by each fall respectively.
W = the weight of the ram.
L = load required to sink the pile further.

$$L = \frac{W(H - h)}{D - d}.$$

Rule for the Weight of Rams.

W = Weight of pile in lbs.
A = Sectional area of pile in inches.
L = Length of pile in feet.
H = Height of fall in feet.
R = Weight of ram in lbs.

$$R = W\left(\frac{W H}{5 A L} - 1\right).$$

A heavy ram with a small fall splits the piles less than a light ram with a large fall.

Nasmyth's Steam Pile Driver.

Weight, 72 cwt.; diameter of cylinder, 16 inches; fall, 3 feet; making 60 blows per minute. It was found that it required 15 blows to drive a pile 1 foot, which was equivalent, in soil of the same character, to 15 blows of an ordinary pile driver with a ram of 15 cwt. falling 16 feet; the ordinary pile driver, however, only made 1 blow in 4 minutes, or $\frac{1}{240}$th of the speed of the steam pile driver.

Sheet Piling.

Birds-mouth bevelling 120°
Angle of shoeing .. 25°, with horizon.

Ringing Engines.

W = From 4 to 8 cwt.
Power to each ringing engine
= 1 man to each 40 lbs. weight of ram.

Foundations.

(Rankine.)

W = Weight of soft ground per unit of volume.
d = Depth of foundation.
a = Angle of friction.
P = Pressure on base per unit of area which will support building

$$= W\,d\left(\frac{1 + \sin. a}{1 - \sin. a}\right)^2.$$

Blows versus Pressure (in shaping or dividing substances).

(Kick, 'Trans. Inst. Civ. Eng.,' vol. xliv.)

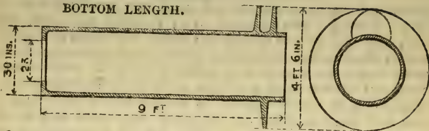
1. More waste of labour is caused by blows than by constant steady pressure.

2. One blow, exercising the same mechanical power as that of a known steady pressure, will not produce an equal effect.

3. The mechanical power necessary to effect temporary alteration of a substance up to its limit of elasticity, if applied through the medium of blows, will not affect that substance up to the limit of elasticity.

Screw Piles.

CAST-IRON SCREW PILE.
BOTTOM LENGTH.



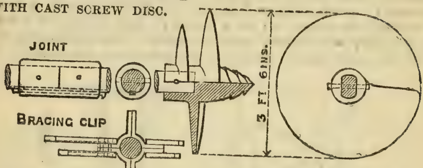
Lengths, 9 feet; diameter, outside, 2 feet 6 inches; metal 1 inch thick; thread of screw, $\frac{5}{8}$ at point, $2\frac{1}{4}$ at root; pitch of screw, 7 inches. Flanges $1\frac{3}{4}$ thick, with 10 bolts 1 inch in diameter. Diameter of screw 4 feet 6 inches, screwed 20 to 45 feet into ground, by 4 levers each 40 feet long, each lever having 8 bullocks yoked to it.

A more manageable arrangement is a capstan head on the pile, with rail arms and ropes passing twice round their ends to a crab-winch.

Weight of bottom length about $1\frac{1}{2}$ ton, intermediate lengths $1\frac{1}{4}$ ton; bracing per bay, about 0·37 tons. A pier of 2 piles 40 feet long with bracing weighs about 16 tons.

Screw Pile Jetties.

SOLID WROUGHT-IRON PILE
WITH CAST SCREW DISC.

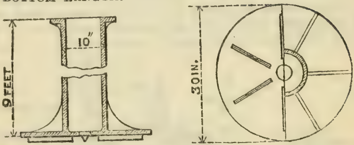


Distance of centres apart, 15 feet; diameter of pile, 6 inches; lengths, 18 to 25 feet; screw, 3 feet 6 inches diameter; 2 feet 6 inches deep; metal at root of blade, $2\frac{1}{2}$ inches thick; diameter of boss, $9\frac{1}{4}$ inches; diameter of coupling, $10\frac{1}{4}$ inches; length of ditto, 21 inches; coupling key, 2×1, recessed $\frac{1}{4}$ inch; steel pin through coupling $1\frac{1}{4}$ inch diameter, $\frac{1}{16}$ inch taper; clips for bracing, 9 inches wide, 10 inches long, $\frac{7}{8}$ inch thick.

Pile, where inserted in shoe, reduced $\frac{1}{4}$ inch on two sides by two flats; bracing of channel iron, $4\frac{1}{2}'' \times 1\frac{1}{2}'' \times \frac{1}{2}''$.

HYDRAULIC PILES.

BOTTOM LENGTH.



These piles were sunk for a railway viaduct over the sands in Morecambe Bay. Spans, 30 feet; two main and two raking piles per pier; rake of piles, 1 in 12. Piles in lengths of 9 feet, 10 inches diameter outside; metal ¾ thick. Diameter of discs of main pile, 30 inches; ditto of raking pile, 18 inches. Sustaining power of sand, about 5 tons per square foot. Average depth sunk below surface of sand, 20 feet; ditto at opening spans, 26 feet; piles defended from scour by a weir of rubble stone.

Orifice at disc, for discharge of water, 2 inches diameter.

MODE OF SINKING.

The piles were sunk from pontoons, each pontoon being filled with a pile engine and a donkey engine about 2 horse-power. Mr. Brunlees recommends for future operations the fitting of the pontoons with sufficient appliances for sinking all the piles of a pier simultaneously. The piles are lashed to the block of the pile engine, which acts as a guide; there is another guide low down on the pontoon; the pile hangs with a loose chain, so that its weight assists in the sinking. When attachment is made with a flexible hose to the donkey engine, and the water pumped in issuing at the orifice washes away the sand in the marly deposit, an alternating rotatory motion is given, by which the cutters cast on the disc loosen the marl and allow it to be washed away. Piles are drawn by pumping and lifting the pile by means of the pile engine. Two piles generally fixed during an ebb tide.

Permanent Loads on Bridges, &c.

For rough calculations the weight of the bridge itself may be assumed to be (in wrought-iron bridges):—

For	30	feet spans,	single line	5 cwt. per foot run
„	60	„	„	6 „ „
„	100	„	„	9 „ „
„	150	„	„	12 „ „
„	200	„	„	15 „ „

Dense crowds average 120 lbs. per square foot.

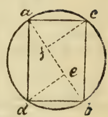
For flooring $1\frac{1}{2}$ to 2 cwt. per square foot, exclusive of the weight of the flooring, is generally allowed.

In store-houses from 2 to 4 cwt. per square foot.

Safe Load in Structures, including Weight of Structure.

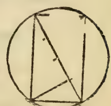
In cast-iron columns	= $\frac{1}{4}$	breaking weight.
Wrought-iron structures ..	= $\frac{1}{4}$	„
In cast-iron girders for tanks	= $\frac{1}{4}$	„
In ditto for bridges and floors	= $\frac{1}{6}$	„
In timber (live load)	= $\frac{1}{10}$	„
„ (dead load)	= $\frac{1}{5}$	„
Stone and bricks	= $\frac{1}{8}$	„

To Cut the best Beam from a Log.



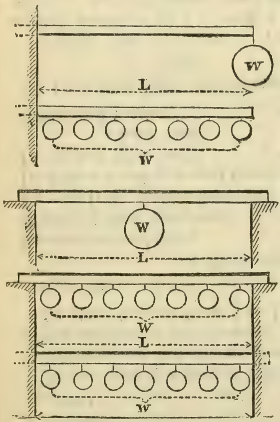
Divide the diameter, $a\ b$, into 3 equal parts, $a\ f$, $f\ e$, and $e\ b$, and from e and f—draw the lines $f\ c$, $e\ d$, at right angles to $a\ b$—join $a\ c$, $a\ d$, $b\ c$, and $b\ d$, then $a\ c\ b\ d$ is the cross-section of the strongest beam.

To cut the stiffest beam, divide the diameter into 4 instead of 3 parts, as shown.



Strength of Rectangular Beams.

L = Length of beam or span. } in inches.
B = Breadth of beam. } in inches.
D = Depth of beam. } in inches.
W = Breaking weight in cwts.
K = Coefficient of rupture (for values of K, see below).
M = Multiplier for deflection (see "Deflection").



	W	K	M
One end fixed. The other loaded.	$\frac{K B D^2}{L}$	$\frac{L W}{B D^2}$	·33
One end fixed. Weight distributed.	$\frac{2 K B D^2}{L}$	$\frac{L W}{2 B D^2}$	·125
Ends supported. Weight in centre.	$\frac{4 K B D^2}{L}$	$\frac{L W}{4 B D^2}$	·02
Ends supported. Weight distributed.	$\frac{8 K B D^2}{L}$	$\frac{L W}{8 B D^2}$	·013
Ends fixed. Weight distributed.	$\frac{12 K B D^2}{L}$	$\frac{L W}{12 B D^2}$	·0022

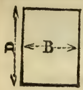
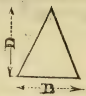
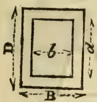
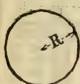
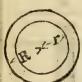
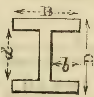
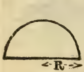
Values of K for Different Materials.

Material.	K cwt.	Material.	K cwt.	Material.	K cwt.
Wrought Iron ..	68	Beech	13	Oak, African ..	22
Cast Iron	46	Cedar, Lebanon	13	„ English	15
Cast Brass	24	„ W. Indies	12	Pine, Red ..	13
Ash, English ..	19	Deal	14	„ Yellow ..	10
„ American..	16	Elm	7	„ Memel ..	12
Birch	17	Fir (spruce) ..	12	Teak	19
		Mahogany	15		

Beams of Various Sections.

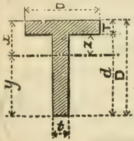
To find the breaking weight of beams of the following sections, use the formula for W in the preceding page, but substituting for $B\,D^2$ the values of V for the section required.

I = Moment of inertia (see "Moment of Inertia").

	RECTANGLE. $I = \frac{B\,D^3}{12}$ $V = B\,D^2$		TRIANGLE. $I = \frac{B\,D^3}{36}$ $V = \frac{B\,D^2}{4}$
	HOLLOW RECTANGLE. $I = \frac{B\,D^3 - b\,d^3}{12}$ $V = \frac{B\,D^3 - b\,d^3}{D}$		ELLIPSE. $I = \cdot 7854\ C\,T^3$ $V = 4 \cdot 7\ C\,T^2$
	CIRCLE. $I = \cdot 7854\ R^4$ $V = 4 \cdot 7\ R^3$		SQUARE. $I = \frac{S^4}{12}$ $V = S^3$
	HOLLOW CIRCLE. $I = \cdot 7854\ (R^4 - r^4)$ $V = 4 \cdot 7 \left(\frac{R^4 - r^4}{R} \right)$		$I = \frac{B\,D^3 - 2\,b\,d^3}{12}$ $V = B\,D^2 - 2\,b\,d^2$
	SEMICIRCLE. $I = \cdot 11\ R^4$ $V = \cdot 38\ R^3$		$I = \frac{B\,D^3 + 2\,b\,d^3}{12}$ $V = B\,D^2 + 2\,b\,d^2$

MOMENT OF INERTIA AND POSITION OF NEUTRAL AXIS.

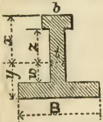
I = Moment of inertia.
y = Distance of neutral axis from bottom of section.



T SECTION.

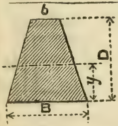
$$y = \frac{d}{2} + \frac{\frac{1}{2}\,BDT}{BT + dt}.$$

$$I = \frac{B(x^3 - z^3) + t(y^3 + z^3)}{3}.$$



DOUBLE FLANGE SECTION.

$$I = \frac{B(y^3 - w^3) + b(x^3 - z^3) + t(w^3 + z^3)}{3}.$$

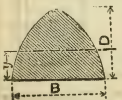


TRAPEZOID.

$$y = \frac{D}{3}\;\frac{B + 2b}{B + b}.$$

$$I = D^3\,\frac{B^2 + 4Bb + b^2}{36\,B + b}.$$

PARABOLIC SEGMENT.

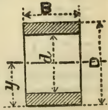


$$y = \frac{2D}{5}.$$

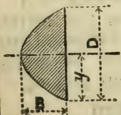
$$I = \frac{D^3 B}{21 \cdot 875}$$

$$y = \frac{D}{2}.$$

$$I = B\,\frac{D^3 - d^3}{12}$$



PARABOLIC SEGMENT.



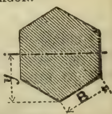
$$y = \frac{D}{2}.$$

$$I = \frac{D^3 B}{30}.$$

HEXAGON.

$$y = B.$$

$$I = \tfrac{5}{16}\,B^4\sqrt{3}.$$
$$= \cdot 541266\,B^4.$$



FOR SIMILAR SECTIONS, D and d = the depths of the given and required sections respectively, and I and i be the moments of inertia, then $i = I\frac{d^4}{D^4}$.

SAFE LOAD DISTRIBUTED ON SQUARE BEAMS OF PINE. (By Graphic Construction.)

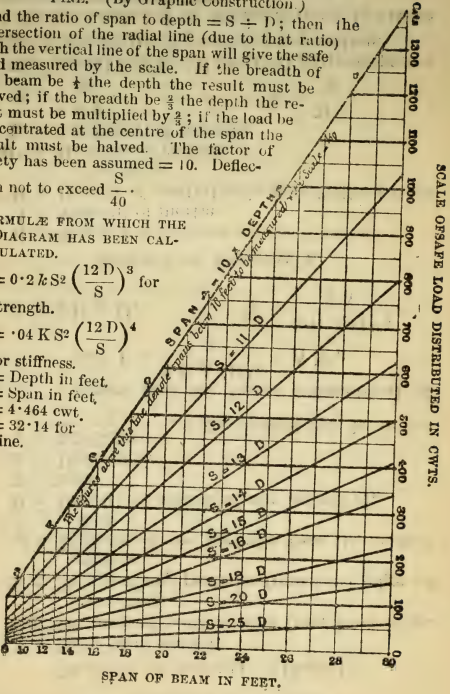
Find the ratio of span to depth $= S \div D$; then the intersection of the radial line (due to that ratio) with the vertical line of the span will give the safe load measured by the scale. If the breadth of the beam be $\frac{1}{2}$ the depth the result must be halved; if the breadth be $\frac{2}{3}$ the depth the result must be multiplied by $\frac{2}{3}$; if the load be concentrated at the centre of the span the result must be halved. The factor of safety has been assumed $= 10$. Deflection not to exceed $\frac{S}{40}$.

FORMULÆ FROM WHICH THE DIAGRAM HAS BEEN CALCULATED.

$L = 0 \cdot 2\, k\, S^2 \left(\frac{12\, D}{S}\right)^3$ for strength.

$L = \cdot 04\, K\, S^2 \left(\frac{12\, D}{S}\right)^4$ for stiffness.

$D =$ Depth in feet.
$S =$ Span in feet.
$k = 4 \cdot 464$ cwt.
$K = 32 \cdot 14$ for pine.



Moment of Inertia. (Heppel)

I = Moment of inertia.
N = Distance of neutral axis from *lower* edge of section.
H = Height of any particles from *lower* edge of section.
d = Distance of any particles from the neutral axis.
B = Breadth of section at any height H.
Σ = Sum.
Δ = Difference.

$I = \frac{2\,\Sigma B\,\Delta\,(d^3)}{3}$, if the neutral axis be in the centre and the figure symmetrical, if not, $I = \frac{\Sigma B\,\Delta\,(H^3)}{3} - A\,N^2$.

$A = \Sigma B\,\Delta\,H$. $\qquad N = \frac{\Sigma B\,\Delta\,(H^2)}{2\,A}$.

Moment of Resistance.

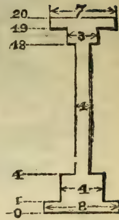
R = Moment of resistance.
I = Moment of inertia.
N = Height of neutral axis from farthest edge of section.
M^* = Modulus of rupture.
K = Coefficient of fracture.

$R = \frac{6\,K\,I}{N}$. $\qquad R = \frac{M\,I}{N}$.

The neutral axis for all practical purposes passes through the centre of gravity of any section.

* For determination of the Moment of Inertia by Graphic Construction, see page after next.

Moment of Inertia. (Heppel.)



Example, showing the practical application of the formulæ given in the preceding page. The more closely the section is divided into minute rectangles, the more accurate will be the result.

H.	H^2.	H^3.	Δ H.	ΔH^2.	$\Delta H(^3)$.	B.	B Δ H.	B$\Delta(H^2)$.	B Δ (H^3).
0	0	0							
1	1	1	1	1	1	8	8	8	8
4	16	64	3	15	63	4	12	60	252
18	324	5832	14	308	5768	1	14	308	5768
19	361	6859	1	37	1027	3	3	111	3081
20	400	8000	1	39	1141	7	7	273	7987
							44 $= \Sigma B \Delta H = A$	760 $\Sigma B \Delta H^2$	17096 $\Sigma B \Delta (H^3)$

$$N = \frac{\Sigma B \Delta (H^2)}{2 A} = \frac{760}{88} = 8 \cdot 63.$$

$$I = \frac{\Sigma B \Delta H^3}{3} - A N^2.$$

$$= \frac{17096}{3} - 44 \times (8 \cdot 63)^2 = 5698 - 3277$$
$$= 2421$$

MOMENT OF INERTIA. (Graphic Construction.)

D = Distance of edge of section from neutral axis.

g = Distance of centre of gravity of each section of the "inertia area" from the neutral axis.

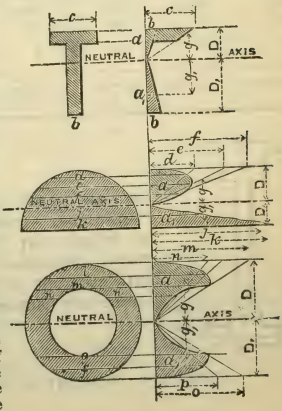
a = Section of "inertia area" above or below neutral axis.

I = Moment of inertia = 2 D $a\,g$ in symmetrical figures.

I = D $a\,g$ + $D_1\,a_1\,g_1$, where D $a\,g$ and $D_1\,a_1\,g_1$ are dimensions respectively above and below the neutral axis in unsymmetrical figures.

To form the "*inertia area*" divide the section into any convenient layers, drawing horizontal lines to represent the layers and neutral axis. On a horizontal line distant D from the neutral axis set off from any vertical line representing the widths of each layer respectively, and from the widths thus set off draw lines radiating to the point of intersection of the vertical line with the neutral axis, then the intersection of these radiating lines with the respective horizontal lines of each layer will give points in the line which limits the "inertia area."

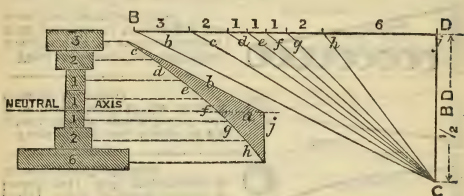
SECTIONS. INERTIA AREAS.



Moment of Inertia. (Graphic Construction.)

Divide the section into convenient layers; then with any scale set out successively on a horizontal line lengths proportional to the area of each layer respectively; making the total length D B = the area of the section; also draw the perpendicular D C = $\frac{1}{2}$ D B; join B C, and from the points set out as above draw vector lines radiating to C. Then from the horizontal lines which pass through the centres of gravity of each layer respectively draw lines parallel to each vector respectively as shown in the diagram, forming a polygon. The intersection of the lines $b\,j$ in the polygon determines the position of the neutral axis.

The lines of the polygon are denoted by the same letters as the vector lines to which they have been drawn parallel.



Then if I = Moment of inertia,
A = Area of the section,
a = Area of the polygon as formed above,
$$I = A\,a.$$

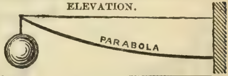
The nearer the layers are together the more accurate will be the result.

BEAMS OF EQUAL STRENGTH throughout their length.

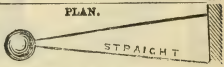
The section is supposed in all cases to be rectangular throughout. The beams shown in plan are of uniform depth throughout. Those shown in elevation are of uniform breadth throughout.

B = Breadth of beam. D = Depth of beam.

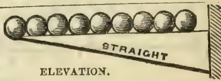
Fixed at one end, loaded at the other; curve parabola, vertex at loaded end; B D^2 proportional to distance from loaded end.



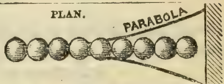
Fixed at one end, loaded at the other; triangle, apex at loaded end; B D^2 proportional to the distance from the loaded end.



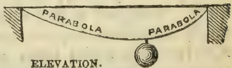
Fixed at one end; load distributed; triangle, apex at unsupported end; B D^2 proportional to square of distance from unsupported end.



Fixed at one end; load distributed; curves two parabolas, vertices touching each other at unsupported end; B D^2 proportional to distance from unsupported end.

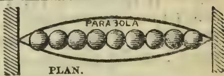


Supported at both ends; load at any one point; two parabolas, vertices at the points of support, bases at point loaded; B D^2 proportional to distance from nearest point of support.

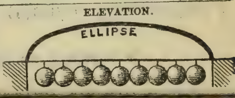


Supported at both ends; load at any one point; two triangles, apices at points of support, bases at point loaded; B D^2 proportional to distance from the nearest point of support.

Supported at both ends; load distributed; curves two parabolas, vertices at the middle of the beam; bases centre line of beam; B D^2 proportional to product of distances from points of support.



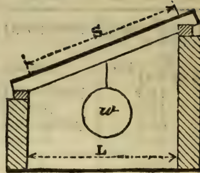
Supported at both ends; load distributed; curve semi-ellipse; B D^2 proportional to the product of the distances from the points of support.



Beams on the Slope.

W = Breaking weight for horizontal beam.
L = Span on horizontal line.
S = Span on slope.
w = Breaking weight of beam on slope.

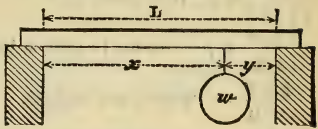
$$w = \frac{W\,S}{L}.$$



Beams Unequally Loaded.

W = Breaking weight for load applied at centre as found by formula.
w = Breaking weight for beam unequally loaded.
L = Length of beam or "span."
x & y = Distances of load from point of support.

$$w = \frac{W\,L^2}{4\,x\,y}.$$



Deflection of Beams.

L = Length of beam.
W = Load on the beam.
I = Moment of inertia due to the section.
E = Force corresponding with modulus of elasticity.
M = Coefficient varying with the mode of supporting the beam and applying the load for values of M.
D = Deflection.

$$D = \frac{W\,L^3\,M}{E\,I}.$$

K 2

DEFLECTION OF BEAMS AND GIRDERS.

L = Length of span.
W = Weight on beam.
I = Moment of inertia.
E = Modulus of elasticity, say 10,000 for cast iron = 13,000 for steel.
S = Stress in tons per square inch on material of beam or girder.
D = Effective depth.
d = Deflection of beam or girder.

One end fixed, the other loaded, $d = \frac{W L^3}{3 E I}$;

" " weight distributed, $d = \frac{W L^3}{8 E I}$.

Ends supported, weight at centre, $d = \frac{W L^3}{48 E I}$,

" " " distributed, $d = \frac{5 W L^3}{384 E I}$.

Ends supported, uniform stress, $d = \frac{S L^2}{4 E D}$.

TRANSVERSE STRENGTH OF PLATES.

Taking the strength of the square plate = 1·00 if supported as a beam on two edges and the load applied at the centre, the following will be the relative strength :—

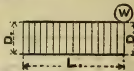
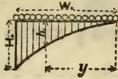
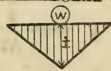
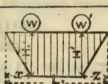
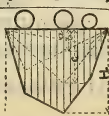
Plate.	How Supported.	Load.	Strength.
Square	4 sides	Central	1·33
Square	4 sides	Distributed	4·00
Circular	All round	Central	1·57
Circular	All round	Distributed	4·71
Oblong	4 sides	Central	$\cdot 67 \frac{l^4 + b^4}{l^4}$ *
Oblong	4 sides	Distributed	$2\cdot 00 \frac{l^4 + b^4}{l^4}$

If firmly riveted to immovable abutments, the strength will be 1·5 times that above given.

Bending Moments and Shearing Forces in Beams.

(Graphic Construction.)

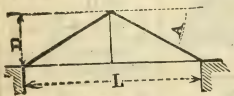
With any convenient scale lay off the distances H, D, or h, as shown in the diagrams, then the moments or forces may be measured off at any part of the span L.

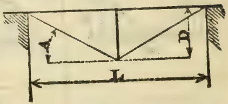
	Bending Moments.	Shearing Forces
1. One end fixed; the other loaded. $H = W L$; $D = W$.		
2. One end fixed; the load distributed. $H = \frac{W L}{2}$; $D = W$. $h = \frac{H y^2}{L^2}$.		
3. Ends supported; load at centre. $H = \frac{W L}{4}$; $D = \frac{W}{2}$.		
4. Ends supported; load distributed. $H = \frac{W L}{8}$; $D = \frac{W}{2}$. $h = H - \frac{H y^2}{(\frac{1}{2} L)^2}$.		
5. Ends supported; load not at centre. $H = \frac{W x y}{L}$; $D = W$		
6. Two equal loads equidistant from centre. $H = W x$; $H' = W' z$ $D = W$; $D' = W'$		
7. Unequal loading. Find the moment of each load as in Case 5. Then $H = a + b + c$. The other points are found in a similar manner.		Find the shearing forces for each case separately as in case (5), and add all ordinates together at any point in the span.

Trussed Beams.

W = Weight distributed.
L = Span of truss.
l = Distance of tie or strut from nearest point of support.
D = Depth of truss.
A = Angle of inclined portion with horizon.
S = Strain on centre of horizontal part of top or bottom.
s = Strain on inclined portions.

Single Truss.

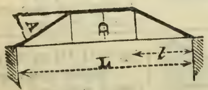


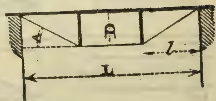


$$S = \frac{W\,L}{8\,D} = \frac{W}{4}\text{ cotan. } A.$$

$$s = S\frac{\sqrt{L^2 + (2\,D)^2}}{L} = \frac{W}{4}\text{ cosect. } A.$$

Queen Truss.





$$S = \frac{L\,W}{8\,D}. \qquad s = S\frac{\sqrt{l^2 + D^2}}{l} = S\text{ sect. } A.$$

The thin lines are in tension; the thick lines in compression.

Stiffness of Beams. (Tredgold.)

B = breadth of beam in inches; D = depth in inches; L = length in feet; and W = load in lbs on middle.

$$D = \sqrt[3]{\frac{L^2 W a}{B}} \qquad a = \cdot 01 \text{ Fir}$$

$a =$	·01	Fir
$=$	·01	Ash
$=$	·013	Beech
$=$	·008	Teak
$=$	·015	Elm
$=$	·02	Mahogany
$=$	·013	Oak

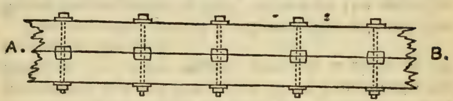
$$B = \frac{L^2 W a}{D^3}$$

When the beam is uniformly loaded, take ·625 W instead of W.

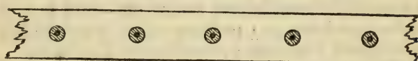
Built Beams.

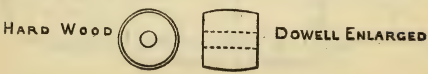
Mode of building beams sometimes adopted in preference to the ordinary method.

Hard-wood dowells are inserted in holes bored with a large centre-bit, the bolt passing through the dowell which is sometimes turned to a very slight double taper to ensure a fit.



Section on Line A. B.





Asphalte Flooring.

1 in.	thick	requires	per super. ft.	$12\frac{1}{2}$	lbs. asphalte.
$\frac{3}{4}$	"	"	"	$9\frac{3}{8}$	"
$\frac{1}{2}$	"	"	"	$6\frac{1}{4}$	"

Asphalte floors should be laid on a good concrete foundation 6 inches deep, of 7 of sharp clean gravel to 1 of lime—no stones larger than a pigeon's egg (about 52 lbs. per superficial foot). The inequalities should be flushed up with fine concrete of 6 of fine gravel (passed through a sieve 5 meshes to the inch) to 1 of lime passed through a sieve of 10 meshes to the inch.

The concrete should be thoroughly set and dry before the asphalte is laid, otherwise the asphalte will blow. Dry ashes should be swept over the surface of the concrete to remove moisture.

The asphalte should be heated with wood—coke is more injurious than coal. The mineral tar should be first put into the caldron and the asphalte broken fine and gradually mixed, stirring well.

An excess of tar should be avoided in the tropics. When the asphalte is ready for use it should give off light puffs of smoke and drop freely from the stirrer. The surface while hot should be sprinkled with chalk powder or fine sand and stamped well.

The asphalte should be laid in widths of about 3 feet; the joints kept clean and free from dust, and heated before laying the next width.

Thickness, $1\frac{1}{4}$ for goods warehouse.
" $\frac{3}{4}$ for railway platforms.
" $\frac{1}{2}$ for arches, &c.

Asphalte should not be used when it is likely to be saturated with oil or grease.

For repairs, pour hot asphalte over the spot and allow it to remain till the part to be removed is softened.

Table of Wooden Flooring, Joists, &c. (Tredgold.)

Length of bearing in feet.	Girders. 10 feet apart, 10 to 12 inch bearing on walls.		Binders. 4 to 6 feet apart, 4 to 6 inch bearing on walls.		Joists. 1 foot apart.		Ceiling Joists. 1 foot apart.	
	Depth.	Breadth	Depth.	Breadth	Depth.	Breadth	Depth.	Breadth
6	—	—	6	4	6	2	$3\frac{1}{2}$	2
8	—	—	7	$4\frac{1}{2}$	7	$2\frac{1}{2}$	4	$2\frac{1}{4}$
10	9	7	8	5	$7\frac{1}{2}$	$2\frac{1}{2}$	5	$2\frac{1}{2}$
12	10	8	9	$5\frac{1}{2}$	8	$2\frac{1}{2}$	6	$2\frac{1}{2}$
14	11	9	10	6	9	$2\frac{1}{2}$	—	—
16	12	10	11	$6\frac{1}{2}$	$10\frac{1}{2}$	$2\frac{1}{2}$	—	—
18	12	11	12	7	12	$2\frac{1}{2}$	—	—
20	13	11	13	$7\frac{1}{2}$	12	3	—	—
24	15	12	—	—	—	—	—	—
26	16	12	—	—	—	—	—	—
28	16	13	—	—	—	—	—	—
30	16	14	—	—	—	—	—	—

When the bearing of the joists exceeds 8 feet, the joists should be strutted with a row of struts for each 4 feet of bearing extra.

For trimming joists, add $\frac{1}{8}$ of an inch in breadth to the dimensions of ordinary joists for each joist supported by the trimmer.

Wall plates from $4\frac{1}{2} \times 3$ to $7\frac{1}{2} \times 5$.

Proportion of Steps in Staircases.

The rise should not be more than 7 inches, nor less than $5\frac{1}{2}$ inches.

The tread should not be more than 12 inches, nor less than 9 inches.

A good proportion is

$$\text{Rise in inches} = \frac{66}{\text{Tread in inches}}.$$

Another rule:—

$$\text{Rise in inches} = 18 - \text{Tread in inches}.$$

Strength and Weight of I Iron Beams.
(Société John Cockerill, Belgium.)

The loads are calculated on a resistance of 10,000 lbs. = $4\frac{1}{4}$ tons per square inch. The load being distributed and the beam supported at both ends. Half the load must be taken if concentrated at the centre.

Dimensions, inches.			Weight, lbs. per foot run.	Load in cwt. for Spans of					
Depth	Flange Width.	Web Thickness.		5 feet.	10 feet.	15 feet.	20 feet.	25 feet.	30 feet.
$3\frac{15}{16}$	2	$\frac{3}{16}$	6·80	28·2	14·1	9·4	7·1	5·7	4·7
$4\frac{11}{16}$	2	$\frac{1}{4}$	8·10	37·2	18·6	12·4	9·3	7·4	6·2
$5\frac{1}{2}$	2	$\frac{1}{4}$	8·80	49·6	24·8	16·5	12·4	9·9	8·3
$3\frac{1}{8}$	$1\frac{9}{16}$	$\frac{5}{32}$	3·90	12·3	6·2	4·1	3·1	2·5	2·1
5	$2\frac{15}{16}$	$\frac{1}{4}$	11·50	68·1	34·1	22·7	17·0	13·6	11·4
$5\frac{1}{2}$	$2\frac{3}{4}$	$\frac{1}{4}$	11·50	71·9	36·0	24·0	18·0	14·4	12·0
$6\frac{5}{16}$	$3\frac{1}{8}$	$\frac{5}{16}$	15·50	110·9	55·5	37·0	27·7	22·2	18·5
$7\frac{1}{16}$	$3\frac{1}{2}$	$\frac{3}{8}$	17·50	134·0	67·0	44·7	33·5	26·8	22·3
$7\frac{7}{8}$	$2\frac{9}{16}$	$\frac{5}{16}$	15·50	120·2	60·1	40·1	32·3	24·0	20·0
$8\frac{5}{8}$	$2\frac{3}{4}$	$\frac{5}{16}$	16·80	146·0	73·0	48 7	36·5	29·2	24·3
$7\frac{1}{16}$	$3\frac{15}{16}$	$\frac{3}{8}$	20·20	162·4	81·2	54·1	40·6	32·5	27·1
$7\frac{7}{8}$	$3\frac{15}{16}$	$\frac{3}{8}$	20·90	177·0	88·5	59·0	44·2	35·4	29·5
$9\frac{1}{4}$	$3\frac{3}{4}$	$\frac{3}{8}$	23·20	229 6	114·8	76·5	57·4	45·9	38·3
$9\frac{7}{8}$	$4\frac{1}{2}$	$\frac{3}{8}$	30·30	304·1	152·0	101·3	76·0	60·8	50·7
$9\frac{1}{4}$	$3\frac{1}{2}$	$\frac{3}{8}$	22·20	214·5	107·3	71·5	53·6	42·9	35·8
8	5	$\frac{3}{8}$	26·90	246·6	123·3	82·2	61·7	49·3	41·1
$9\frac{5}{16}$	$3\frac{5}{8}$	$\frac{5}{16}$	20·20	199·1	99·6	66·4	49·8	39·8	33·2
$11\frac{13}{16}$	$4\frac{15}{16}$	$\frac{7}{16}$	39 70	515·4	257·7	171·8	128·6	103·1	85 9
$12\frac{1}{2}$	$6\frac{1}{4}$	$\frac{11}{16}$	60·50	820·5	410·3	273·5	205·1	164·1	136·8
12	$5\frac{15}{16}$	$\frac{11}{16}$	53·80	714·5	357·3	238·2	179·2	142·9	119·1

These beams may be rolled $\frac{1}{16}$ or $\frac{1}{8}$ wider, making the web thicker and the flanges wider by that amount.

Strength and Weight of I STEEL Beams.

(Rolled by the Société John Cockerill, Belgium.)

The loads are calculated on a resistance of 14,000 lbs. ($6\frac{1}{4}$ tons) per square inch. The loads being distributed and the beam supported at both ends. Half the load must be taken if concentrated at the centre.

Dimensions, inches.			Weight, lbs. per foot run.	Load in cwt. for Spans of					
Depth	Flange Web.								
	Width.	Thickness.		5 feet.	10 feet.	15 feet.	20 feet.	25 feet.	30 feet.
$3\frac{15}{16}$	2	$\frac{3}{16}$	7·10	39·6	19·8	13·2	9·9	7·9	6·6
$4\frac{11}{16}$	2	$\frac{1}{4}$	8·50	52·1	26·1	17·4	13·0	10·4	8·7
$5\frac{1}{2}$	2	$\frac{1}{4}$	9·20	69·4	34·7	23·1	17·3	13·9	11·6
$3\frac{1}{8}$	$1\frac{9}{16}$	$\frac{5}{32}$	4·10	17·2	8·6	5·7	4·3	3·4	2·9
5	$2\frac{15}{16}$	$\frac{1}{4}$	12·10	95·4	47·7	31·8	23·8	19·1	15·9
$5\frac{1}{2}$	$2\frac{3}{4}$	$\frac{1}{4}$	12·10	100·7	50·4	33·6	25·1	20·0	16·9
$6\frac{5}{16}$	$3\frac{1}{8}$	$\frac{5}{16}$	16·30	155·3	77·6	51·8	38·8	31·1	25·9
$7\frac{1}{16}$	$3\frac{1}{2}$	$\frac{3}{8}$	18·30	187·6	93·8	62·5	46·9	37·5	31·3
$7\frac{7}{8}$	$2\frac{9}{16}$	$\frac{5}{16}$	16·30	168·2	84·1	56·1	42·1	33·7	28·0
$8\frac{5}{8}$	$2\frac{3}{4}$	$\frac{5}{16}$	17·50	204·4	102·0	68·1	51·1	40·9	34·1
$7\frac{1}{16}$	$3\frac{15}{16}$	$\frac{3}{8}$	21·20	227·4	113·7	75·8	56·8	45·5	38·3

Fire-proof Floors.

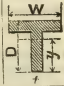
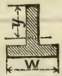
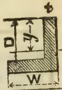
French System with Wrought-iron Rolled Beams.

Length of Bearing.	Depth of Joist.	Depth of Floor complete.	Weight per Square.
feet.	inches.	inches.	lbs.
10 to $11\frac{1}{2}$	4	$7\frac{1}{8}$	370
$11\frac{1}{2}$ to 13	$4\frac{3}{4}$	$7\frac{1}{8}$	420
13 to 16	$5\frac{1}{2}$	$8\frac{5}{8}$	465
16 to 20	$6\frac{1}{4}$	$9\frac{1}{2}$	510
20 to 23	$7\frac{1}{8}$	$10\frac{1}{4}$	605
23 to 26	$8\frac{5}{8}$	$11\frac{3}{4}$	700

STRENGTH OF T AND L IRON. (Captain Broadbent, R.E.)

S = Span in feet. I = Moment of inertia.
y = Distance of neutral axis from farthest edge of the section.
K = Coefficient for each section (see Table).
l = Safe load distributed in lbs. per ft. run, including weight of iron.
L = Total load in lbs. distributed over span, " " "

$L = \frac{K}{S}$; $l = \frac{K}{S^2}$.

Dimensions of Section. Inches.			Values of		Values of K for different Sections and Positions.			
Width, W.	Depth, D.	Thickness.	I.	y.				
4	4	$\frac{1}{2}$	5·5641	2·816	14,750	11,800	11,062	8,850
3	4	$\frac{1}{2}$	5·0485	2·6731	14,102	11,282	10,576	8,461
4	3	$\frac{1}{2}$	2·4234	2·1731	8,327	6,662	6,245	4,996
$3\frac{1}{2}$	$3\frac{1}{2}$	$\frac{1}{2}$	3·635	2·4423	11,113	8,890	8,335	6,668
$3\frac{1}{2}$	$3\frac{1}{2}$	$\frac{3}{8}$	2·865	2·487	8,602	6,882	6,451	5,161
3	3	$\frac{1}{2}$	2·164	2·0682	7,813	6,250	5,860	4,688
3	3	$\frac{3}{8}$	1·7597	2·1125	6,220	4,976	4,665	3,732
$2\frac{1}{2}$	$2\frac{1}{2}$	$\frac{1}{2}$	1·2274	1·6945	5,408	4,326	4,056	3,245
$2\frac{1}{2}$	$2\frac{1}{2}$	$\frac{3}{8}$	·9838	1·7382	4,226	3,381	3,170	2,536
$2\frac{1}{2}$	$2\frac{1}{2}$	$\frac{5}{16}$	·84861	1·7604	3,600	2,881	2,701	2,160
$2\frac{1}{2}$	$2\frac{1}{2}$	$\frac{1}{4}$	·7031	1·7829	2,945	2,356	2,209	1,767
2	2	$\frac{1}{2}$	·59	1·3214	3,334	2,667	2,500	2,000
2	2	$\frac{3}{8}$	·4791	1·3642	2,622	2,098	1,966	1,573
2	2	$\frac{5}{16}$	·41625	1·3861	2,242	1,794	1,682	1,345
2	2	$\frac{1}{4}$	·3476	1·4083	1,843	1,474	1,382	1,106
$1\frac{1}{2}$	$1\frac{1}{2}$	$\frac{3}{8}$	·1867	·9911	1,407	1,126	1,055	844
$1\frac{1}{2}$	$1\frac{1}{2}$	$\frac{5}{16}$	·16393	1·01235	1,209	967	908	725
$1\frac{1}{2}$	$1\frac{1}{2}$	$\frac{1}{4}$	·1385	1·0341	1,000	800	750	600
$1\frac{1}{2}$	$1\frac{1}{2}$	$\frac{3}{16}$	·10998	1·05625	777	622	583	466
$1\frac{1}{2}$	$1\frac{1}{2}$	$\frac{1}{8}$	·0778	1·0788	538	430	403	323

For values of I and K, in sections similar to those above given: If I_1, K_1, and D_1 be the values for the required section, then $I_1 = I\,\frac{D_1{}^4}{D^4}$, and $K_1 = K\,\frac{D_1{}^3}{D^3}$. Example: find I_1 and K_1 for $4 \times 4 \times \frac{3}{8}$ T. I and K for $2 \times 2 \times \frac{5}{16} =$ ·41625 and ·2242 respectively. Therefore, $I_1 = \cdot 41625\,\frac{256}{16} = 6\cdot 66$; and $K_1 = 2242\,\frac{64}{8} = 17936$.

Angles of Roofs.

Proportion of Rise to Span.	Angle. ° ′	Slope.	Proportion of Rise to Span.	Angle. ° ′	Slope.
$\frac{1}{6}$	18 25	3 to 1	$\frac{2}{3}$	53 00	$\frac{3}{4}$ to 1
$\frac{1}{4}$	26 35	2 to 1	$\frac{3}{4}$	56 20	$\frac{2}{3}$ to 1
$\frac{1}{3}$	33 42	$1\frac{1}{2}$ to 1	1	63 30	$\frac{1}{2}$ to 1
$\frac{1}{2}$	45 00	1 to 1	—	—	—

Load on Roofs.

Exclusive of Framing.

	Per Square of 100 supl. feet.	Minimum slope.
Lead covering weighs	7 cwt	4°′
Zinc	$1\frac{1}{2}$ „	4°
Corrugated iron	3 „	4°
Slates	$7\frac{1}{2}$ to 9 „	$25\frac{1}{2}$° to 30°
Tiles	8 to 15 „	$26\frac{1}{2}$° to 30°
Boarding, $\frac{3}{4}$ thick	$2\frac{1}{2}$ „	25°
Ditto, $1\frac{1}{4}$ thick	5 „	—
Timber framing for slated or tiled roofs	5 to 6 „	—
Additional load for pressure of wind	36 „	—
Steepest angle of Gothic roofs		60°

Pressure of Wind on Roofs. (Unwin.)

a = Angle of surface of roof with direction of wind.
F = Force of wind in lbs. per square foot
A = Pressure normal to surface of roof = $F. \sin. a^{1{\cdot}84 \cos. a-1}$
C = Ditto, parallel to direction of wind = $F. \sin. a^{1{\cdot}84 \cos. a}$
B = Ditto, perpendicular to do. do. = $F. \cot. a \sin. a^{1{\cdot}84 \cos. a}$

Angle of roof=a	5°	10°	20°	30°	40°	50°	60°	70°	80°	90°
A = F ×	·125	·24	·45	·66	·83	·95	1·00	1·02	1·01	1·00
B = F ×	·122	·24	·42	·57	·64	·61	·50	·35	·17	·00
C = F ×	·01	·04	·15	·33	·53	·73	·85	·96	·99	1·00

Corrugated Iron Roofing.

B. Wire Gauge.	Size of Sheets.	Weight per square.	Sq. feet per ton.
	feet	cwt. qrs. lbs.	
No. 16 ..	6×2 to 8×3	3 0 14	800
" 18 ..	6×2 to 8×3	2 1 6	1000
" 20 ..	6×2 to 8×3	1 3 6	1250
" 22 ..	6×2 to $7\times2\frac{1}{2}$	1 2 7	1550
" 24 ..	6×2 to $7\times2\frac{1}{2}$	1 0 24	1880
" 26 ..	6×2 to $7\times2\frac{1}{2}$	1 0 6	2170

$\frac{1}{10}$th of the weight to be added for lappage.

Sheets should overlap about 6 inches, and be double riveted at joints.

3 lbs. of rivets required per square of roofing.

Purlins should be about 6 feet apart.

Curved roofs may be made up to 20 feet span without framing; tie-rods 12 feet apart.

Curved Roofs.

Curved roofs are made up to 30 feet span, with 20 feet radius of 18 B. W. G. corrugated iron without trusses.

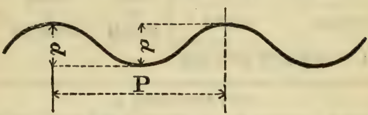
Tie-rods, 2 inches × $\frac{3}{4}$ inch or $\frac{3}{4}$ diameter, 6 feet 4 inches apart; king-rods $\frac{5}{8}$ diameter, eaves stiffened by angle-iron $2\frac{1}{2} \times 2\frac{1}{2} \times \frac{1}{2}$, and top strengthened by an angle-iron $1\frac{1}{2} \times 1\frac{1}{2} \times \frac{1}{2}$ running along the under surface of the corrugated iron on each side of the king-rods.

Corrugated Iron. Transverse Strength.

l = Unsupported length of plate in inches.
t = Thickness of plate in inches.
b = Breadth of plate in inches.
d = Depth of corrugations in inches.
W = Breaking weight distributed in tons.
w = " " " cwts.

$$W = \frac{44.6\,t\,b\,d}{l}\,;\; w = \frac{892\,t\,b\,d}{l}.$$

Proportion of Pitch to depth of Corrugations.



$$d = \frac{P}{4}.$$

From 21 to 26 B. W. G. the pitch P is usually 3 inches. For 20 B. W. gauge and under P is usually 5 inches. 18 or 20 B. W. G. is a good gauge for ordinary roofing; all bolts, screws, or rivets must be in the ridges and not in the valleys of the corrugations, otherwise the roof will leak.

Sheet Lead.

For aprons, 5 lbs. per foot superficial.
For roofs, flats, gutters, &c., 7 to 8 lbs.
Hips and ridges, 6 to 8 lbs.

BUCKLED PLATES.

The resistance of square buckled plates bolted or riveted down all round, is double the resistance of the same plate merely supported all round, and if the two opposite sides be wholly unsupported its resistance is reduced in the proportion of 8 to 5.

The stiffness of buckled plates is as the square of the thickness, and inversely as the curvature.

Two inches curvature suffices for 4 feet square and $\frac{1}{4}$ inch thick.

Ordinary plates are made 3 feet and 4 feet square.

WEIGHT AND SAFE LOAD OF BUCKLED PLATES, 3 FEET SQUARE.

No.	Thickness of Metal.	Weight in Lbs.	Safe Load distributed in Tons.			
			Passive.		Impulsive.	
			Per Plate.	Per Sq. Ft.	Per Plate.	Per Sq. Ft.
1	18 B.W.G.	17·3	·27	·03	·20	·022
2	16	23·6	·43	·048	·32	·036
3	12	38·7	·64	·071	·48	·053
4	$\frac{1}{8}$ in.	45·0	1·00	·112	·75	·083
5	$\frac{3}{16}$ "	67·5	2·5	·278	1·7	·189
6	$\frac{1}{4}$ "	90·0	4·5	·5	3·0	·333
7	$\frac{5}{16}$ "	112·5	6·2	·689	4·7	·522
8	$\frac{3}{8}$ "	135·0	9·0	1·0	6·8	·755

The safe load may be doubled for buckled plates of puddled steel.

SLATES.

Table of Sizes and Weights of Slates, exclusive of Laths.

Names.	Sizes.	Squares covered by 1000.	Weight of 1000.	Weight per Square.
			cwts.	cwts.
Doubles ..	13 × 6	2	15	$7\frac{1}{2}$
Ladies ..	16 × 8	$4\frac{1}{2}$	25	$5\frac{3}{4}$
Countesses	20 × 10	7	40	$5\frac{3}{4}$
Duchesses	24 × 12	10	60	6

WOODEN ROOFS. (Principals 10 feet apart.)

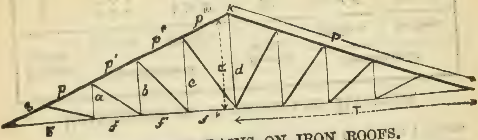
Span in feet.	Principal.	Tie-beam.	King-posts.	Queen-posts.	Small Queens.	Straining Beam.	Struts.
20	4×4	9×4	4×4	—	—	—	3 ×3
25	5×4	10×5	5×5	—	—	—	5 ×3
30	6×4	11×6	6×6	—	—	—	6 ×3
*35	5×4	11×4	—	4×4	—	7×4	4 ×2
45	6×5	13×6	—	6×6	—	7×6	5 ×3
50	8×6	13×8	—	8×8	8×4	9×6	5 ×3
55	8×7	14×9	—	9×8	9×4	10×6	$5\frac{1}{2}$×3
60	8×8	15×10	—	10×8	10×4	11×6	6 ×3

* The roofs above 30 feet span are calculated as Queen Trusses

SCANTLINGS OF PURLINS AND RAFTERS.

Bearing in feet.	Scantlings of		Bearing in feet.	Scantlings of	
	Purlins.	Rafters.		Purlins.	Rafters.
6	6 × 4	4 × 2	10	8 × 6	6 × $2\frac{1}{2}$
8	7 × 5	4 × $2\frac{1}{2}$	12	9 × 7	6 × $2\frac{1}{2}$

STRAINS ON ROOFS.



RULE FOR STRAINS ON IRON ROOFS.

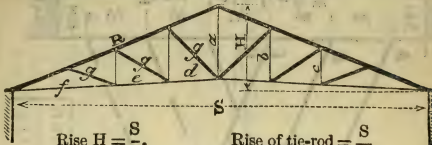
Thick lines in compression.
Fine lines in tension.
P = Length of principal rafter.
R = Rise of roof from centre of tie-rod.
T = Length of $\frac{1}{2}$ tie-rod.
L = Load on truss, including weight of framing.
N = Number of bays formed by the intersection of struts and ties with the principal rafters; in the diagram N = 10.
S = Strain at end of principal rafter.
F = Strain at end of tie-rod.

$S = \dfrac{L P (N-1)}{2 R N}$	$F = \dfrac{L T (N-1)}{2 R N}$
Strain at $p = S - \dfrac{S}{N-1}$	Strain at $f = F - \dfrac{F}{N-1}$
„ $p' = S - \dfrac{2S}{N-1}$	„ $f' = F - \dfrac{2F}{N-1}$
„ $p'' = S - \dfrac{3S}{N-1}$	„ $f'' = F - \dfrac{3F}{N-1}$
„ $p''' = S - \dfrac{4S}{N-1}$	

STRAINS ON KING AND QUEEN RODS.

at $a = \dfrac{L}{2N}$	at $c = \dfrac{1 \cdot 5 L}{N}$
$b = \dfrac{L}{N}$	$d = \dfrac{4L}{N}$

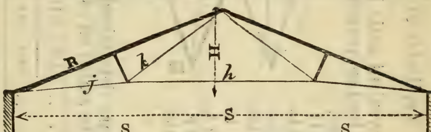
Examples of Iron Roofs. (From actual Practice.)



Rise $H = \frac{S}{5}$.   Rise of tie-rod $= \frac{S}{40}$.

Principals 6 feet 8 inches apart.

Span.	Rafter R.	Struts.	King and Queen bolts.			Tie-rod.		
8 feet.	T-iron.	T-iron.	*a.*	*b.*	*c.*	*d.*	*e.*	*f.*
20	$2\frac{1}{2} \times 2 \times \frac{3}{8}$	$2 \times 2 \times \frac{3}{8}$	$\frac{3}{4}$	$\frac{5}{8}$		$\frac{5}{8}$	$\frac{3}{4}$	
25	$2\frac{3}{4} \times 2\frac{1}{2} \times \frac{3}{8}$	$2 \times 2 \times \frac{3}{8}$	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{7}{8}$	1	
30	$2\frac{3}{4} \times 2\frac{1}{2} \times \frac{1}{2}$	$2\frac{1}{2} \times 2\frac{1}{2} \times \frac{3}{8}$	1	$\frac{3}{4}$	$\frac{5}{8}$	1	$1\frac{1}{8}$	
35	$3 \times 2\frac{3}{4} \times \frac{1}{2}$	$2\frac{1}{2} \times 2\frac{1}{2} \times \frac{3}{8}$	1	$\frac{3}{4}$	$\frac{3}{4}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$
40	$3\frac{1}{2} \times 3 \times \frac{1}{2}$	$2\frac{1}{2} \times 2\frac{1}{2} \times \frac{5}{8}$	$1\frac{1}{8}$	$\frac{7}{8}$	$\frac{3}{4}$	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$
45	$4 \times 3\frac{1}{2} \times \frac{1}{2}$	$3 \times 3 \times \frac{1}{2}$	$1\frac{1}{4}$	1	$\frac{7}{8}$	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$
50	$4 \times 3\frac{1}{2} \times \frac{5}{8}$	$3 \times 3 \times \frac{5}{8}$	$1\frac{3}{4}$	1	$\frac{7}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$
55	$5 \times 4\frac{1}{2} \times \frac{5}{8}$	$4 \times 4 \times \frac{1}{2}$	$1\frac{3}{8}$	$1\frac{1}{8}$	1	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{5}{8}$
60	$5 \times 4\frac{1}{2} \times \frac{3}{4}$	$4 \times 4 \times \frac{5}{8}$	$1\frac{3}{8}$	$1\frac{1}{8}$	1	$1\frac{1}{2}$	$1\frac{5}{8}$	$1\frac{3}{4}$

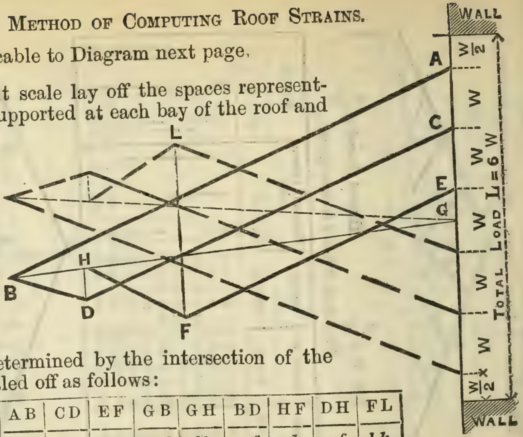


$H = \frac{S}{5}$.   Rise of tie-rod $= \frac{S}{30}$.

Span.	Rafter T-iron.	*h.*	*j.*	*k.*
feet.				
20	$2\frac{1}{2} \times 2 \times \frac{3}{8}$	$\frac{5}{8}$	$\frac{7}{8}$	$\frac{5}{8}$
25	$2\frac{3}{4} \times 2 \times \frac{3}{8}$	$\frac{3}{4}$	1	$\frac{3}{4}$
30	$2\frac{3}{4} \times 2\frac{1}{2} \times \frac{1}{2}$	$2\frac{1}{4} \times \frac{1}{4}$	$2\frac{1}{4} \times \frac{3}{8}$	$2\frac{1}{4} \times \frac{1}{4}$
35	$3 \times 2\frac{3}{4} \times \frac{1}{2}$	$2\frac{1}{2} \times \frac{5}{16}$	$2\frac{1}{2} \times \frac{1}{2}$	$2\frac{1}{2} \times \frac{5}{16}$
40	$3\frac{1}{2} \times 3 \times \frac{1}{2}$	$2\frac{1}{2} \times \frac{3}{8}$	$2\frac{1}{2} \times \frac{5}{8}$	$2\frac{1}{2} \times \frac{3}{8}$
45	$4 \times 3\frac{1}{2} \times \frac{1}{2}$	$3 \times \frac{3}{8}$	$3 \times \frac{1}{2}$	$3 \times \frac{3}{8}$

Clark Maxwell's Method of Computing Roof Strains.

Applicable to Diagram next page.



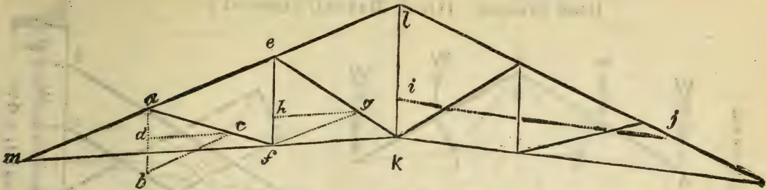
With any convenient scale lay off the spaces representing the vertical load supported at each bay of the roof and wall respectively. Draw AB, CD and EF parallel to the rafter *m l* (see next page), also GB parallel to the tie-rod *m k*, and BD, DH, HF, and FL parallel to *af*, *fe*, *ek*, *kl* respectively.

The strains are determined by the intersection of the lines, and may be scaled off as follows:

The length of	AB	CD	EF	GB	GH	BD	HF	DH	FL
= Strain on	*ma*	*ae*	*el*	*mf*	*fk*	*af*	*ek*	*ef*	*lk*

The fine lines are in tension, the thick in compression.

Computation of Strains on Roofs by Construction.



Let L = Total load on truss. N = Number of bays formed by the intersection of the struts with the rafters = 6 in the diagram.

$$W = \frac{L}{N} = \frac{\text{Load}}{6} \text{ in the diagram.}$$

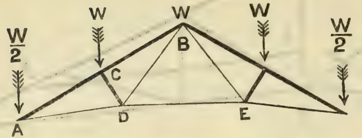
At a with any convenient scale lay off the perpendicular line $a\,b = W$ on the scale of units; from b draw $b\,c$ parallel to the rafter, intersecting the strut at c, and from c draw $c\,d$ parallel with the tie-rod.

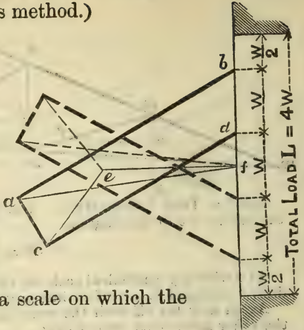
Again at e lay off with the same scale $e\,f = W + a\,d$, and draw as before $f\,g$, $g\,h$ parallel with the rafter and tie-rod respectively.

Again at l lay off $l\,i = \frac{1}{2} W + e\,h$, and from i draw $i\,j$ parallel to the tie-rod until it intersects the rafter at j; the strains may be measured off with the scale as follows:—

Thrust on the Rafter.	Strains on Tie-rod.	Thrust on Struts.	Strains on King and Queen Rods.
Between l & $e = l\,j$.	Between k & $f = i\,j + g\,h$.	Between e & $k = e\,g$.	King $= 2\,e\,f$.
„ e & $a = l\,j + g\,f$.	„ f & $m = i\,j + g\,h + c\,d$.	„ a & $f = a\,c$.	Queen $= a\,d$.
„ a & $m = l\,j + g\,f + c\,b$.			

Roof Strains. (Clark Maxwell's method.)





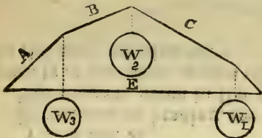
Draw $a\,b$ and $c\,d$ parallel to A B.
" $a\,f$ " A D.
" $a\,c$ " C D.
" $c\,e$ " D B.
" $e\,f$ " D E.

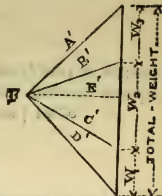
The strains may then be scaled off by a scale on which the total load = L, as follows:

The length of ..	*a b*	*c d*	*a f*	*e f*	*a c*	*c e*
= Strains on ..	A C	C B	A D	D E	C D	D B

The fine lines are in tension, the thick in compression.

Strains on a Polygonal Framing.



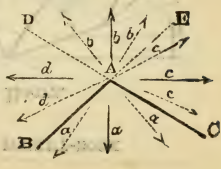


Set out on a perpendicular line with any scale a number of units = total weight, and from the ends of this line lay off A′ parallel to A, and D′ parallel to D, and from their intersection F lay off B′ and C′ parallel to B and C. The portions cut off by the intersection of these lines with the vertical line represent the weights at each point, W_1, W_2, and W_3, required to keep the framing in equilibrio; and the lengths A′, B′, C′, &c., represent the strains on A, B, C, &c.

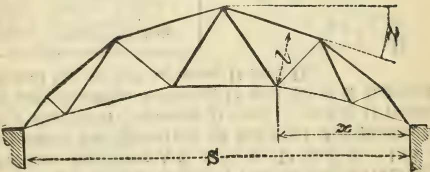
To Determine the Character of any Strain.

Let A B and A C be any two bars of a framing. Produce the lines A B, A C, to D and E. Let *a* represent the direction of the load if it passes in any direction between B and C, or *b* if it passes in any direction between D and E; *c* if between E and C; or *d* if between B and D.

Direction of Load.	Character of Strain	
	On A B.	On A C.
a	Compression	Compression
b	Tension	Tension
c	Tension	Compression
d	Compression	Tension



CURVED ROOFS.



$S =$ Span of girder.
$W =$ Weight distributed.
$R =$ Strain on any bay of top or bottom flange.
$x =$ Distance of apex of any bay from the nearest point of support.
$l =$ Length of perpendicular from base of bay to apex.
$z =$ Angle of any bay of the flange with horizon.
$V =$ Vertical component of strain in any bay.

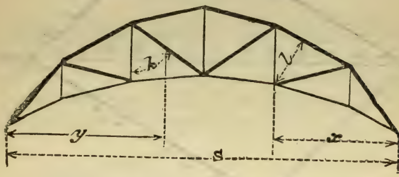
$$R = \frac{W x (S - x)}{2 S l}.$$

$$V = R \sin. Z.$$

For strains on bracing, see next page.

The diagram given in the next page is another variety of the same species of roof, and is subject to the same calculations.

CURVED ROOFS—*continued.*



r = Strain on any brace.
y = Distance of centre of brace from nearest point of support.
F = Shearing force on girder at y.
V = Vertical component of strain in that bay of top flange to which the brace is the diagonal (for value of V =, see preceding page).
v = Vertical component ditto ditto of bottom flange, &c.
k = Angle of brace with vertical line.

$r = (F + v - V)$ secant k. $F = \frac{W}{S}\left(\frac{S}{2} - y\right)$.

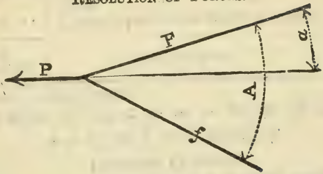
STRAIN ON BRACES IN ANY OTHER FORM OF CURVED GIRDER.

$$r = (F \mp V \pm v) \text{ secant } k.$$

The signs of either + or − are to be prefixed to V and v as follows:—

If the flange be in	And is inclined	The sign is to be
Tension ..	Towards the nearest point of support	+
" ..	From " "	−
Compression	Towards " "	−
"	From " "	+

Resolution of Forces.



F = A force acting in one direction.
f = „ „ in another direction.
P = Resultant force of F and f combined.
A = Angle of direction of F with f
a = Angle of P with F.

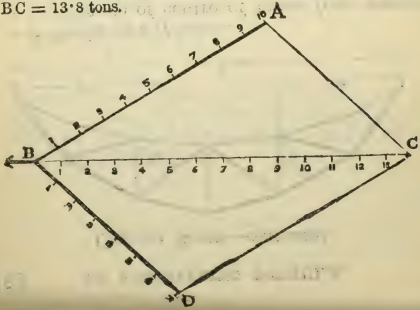
$$P = \sqrt{F^2 + f^2 + (2\,F f \cos. A)}.$$

$$P = \sqrt{F^2 + f^2 - (2\,F f \cos. 180^\circ - A)} \text{ when A exceeds } 90^\circ.$$

$$\text{Sin. } a = \frac{f \sin. A}{P}. \qquad f = \frac{P \sin. a}{\sin. A}$$

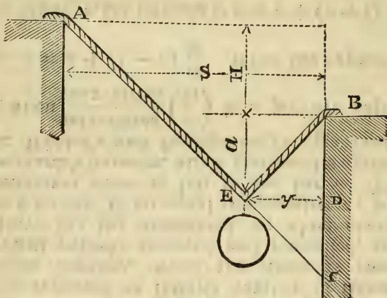
By Parallelogram of Forces.

Measure by any scale on each line their respective units of force, and complete the parallelogram; the diagonal represents the force and direction of the resultant. In the diagram two forces, A B = 10 tons and B D = 7 tons, give a resultant of B C = 13·8 tons.



Weighted Cord.

To find the position a weight will take on a cord. Let A and B be the points of suspension. Lay off A C = length of cord; bisect B C in D; the intersection of the horizontal line D E with A C will give the required position.



L = Length of rope.
S = Span.
H = Height of one support above the other.

$$a = \frac{\sqrt{(L+S)(L-S)} - H}{2}.$$

$$y = \frac{a\,S}{\sqrt{(L+S)(L-S)}}.$$

Varying Stress in Iron and Steel.

(T. W. Fowler.)

By Wöhler's law rupture may be caused not only by a steady stress exceeding the breaking strength of the material, but also by repeated applications of stresses, none of which are equal to this stress. The greater the variation of stress, the less is the stress necessary to produce rupture. Call the stresses which would have to be repeated an infinite number of times to produce fracture, when the stress is steady, t; when entirely removed and reapplied, so as to leave the bar unstrained, u; when changed from a tension to an equal compression, s; when a minimum stress is left in the bar, a. Then Hannhardt's formulæ, which give results agreeing with Wöhler's and Spaugenberg's experiments, are, when $\frac{\text{min. stress}}{\text{max. stress}}\left(\frac{m}{\text{M}}\right)$ is a positive expression, $a = u + (t - u)\frac{m}{\text{M}}$. When the expression $\frac{m}{\text{M}}$ is negative, the formula is $a = u + (u - s)\frac{m}{\text{M}}$. In using this, it is important to remember that the latter part is a negative expression. The values of these constants in tons per square inch, deduced from Wöhler's experiments, are :—

Wrought iron	$t = 20 \cdot 84$	$u = 13 \cdot 94$	$s = 7 \cdot 43$
Krupp's steel	$t = 46 \cdot 6$	$u = 22 \cdot 28$	$s = 13 \cdot 02$

These values are given in Weyrauch's work on 'The Structure of Iron and Steel' reduced

to British units. When Weyrauch wrote, the tension experiments alone were completed. A factor of safety of 3 is ample when these results are allowed for.

VALUES OF a IN TONS PER SQUARE INCH.

Min. ÷ max. stress	1·0	·9	·8	·7	·6
a (wrought iron)	20·8	20·2	19·5	18·8	18·1
a (Krupp's cast steel)	46·4	44·2	41·8	39·3	36·9
Min. ÷ max. stress	·5	·4	·3	·2	·1
a (wrought iron)	17·4	16·7	16·0	15·3	14·6
a (Krupp's cast steel)	34·5	32·0	29·6	27·1	24·7
Min. ÷ max. stress	−0·1	−0·2	−0·3	−0·4	−0·5
a (wrought iron)	13·3	12·6	12·0	11·3	10·7
a (Krupp's cast steel)	21·3	20·4	19·5	18·6	17·6
Min. ÷ max. stress	−0·6	−0·7	−0·8	−0·9	−1·0
a (wrought iron)	10·0	9·4	8·7	8·1	7·4
a (Krupp's cast steel)	16·7	15·8	14·9	14·0	13·0

Ordinary Sizes of Wrought Iron.

LIMITS THAT MAY BE USED WITHOUT INCREASE OF COST.

BAR IRON.

Limit of weight, 4 cwt.
" length, 30 to 35 feet.
" width, flat bars, 6 inches.

L AND T BARS.

Limit of weight, 4 cwt.
" length, 35 feet.
" the sum of the breadth and depth, $8\frac{1}{2}$ in.

CHANNEL IRON OR ROLLED BEAMS.

Limit of weight, 4 cwt.
" length, 35 feet.
" depth, 7 inches.

PLATES.

Limit of weight, 4 cwt.
" length, 15 feet.
" area, 28 superficial feet.
" width, 4 feet.

Beyond the above limits extra prices have to be paid.

MAXIMUM DIMENSIONS ORDINARILY MANUFACTURED.

Flat bars, 12 inches wide.

L bars, 6 in. × 6 in. × $\frac{7}{8}$.

Plates, 7 feet wide or 30 feet long, or 60 superficial feet area.

Roughly the comparative cost of bars and plates may be assumed as follows:—

Flat, round, or square bars being	1·00
L and T Bars	1·12
Plates	1·18

LOADS ON AMERICAN RAILWAY BRIDGES.

American Society Civil Engineers, June 1872.
(Griffin and Clarke.)

In America it is sometimes the practice to double the live load for the calculation of girder strains, varying the stress per square inch in proportion to the ratio of dead to live load.

LOADS PER FOOT RUN ADOPTED RECENTLY IN AMERICA AS A BASIS FOR CALCULATING GIRDER STRAINS.

Span in Feet.	Dead Load in Tons per Foot Run.	Live Load × 2 Tons per Foot Run.	Total Load in Tons per Foot Run.
From 0 to 12	·22	4·46	4·68
12 „ 17	·25	3·57	3·82
17 „ 25	·28	3·12	3·40
25 „ 50	·31	2·68	2·99
50 „ 83	·36	2·48	2·84
100	·40	2·23	2·63
110	·49	2·17	2·66
125	·51	2·11	2·62
150	·55	2·03	2·58
175	·58	1·96	2·54
200	·67	1·90	2·57
225	·76	1·87	2·63
250	·89	1·85	2·84
300	1·07	1·81	2·88
350	1·34	1·78	3·12
400	1·79	1·78	3·57

TO FIND THE STRAIN ON TOP OR BOTTOM BOOMS OF GIRDERS OF DIFFERENT DEPTH (LOAD DISTRIBUTED).

D = Depth of Girder. L = Load distributed.
S = Strain on top and bottom booms.

D=	$\frac{1}{6}$	$\frac{1}{7}$	$\frac{1}{8}$	$\frac{1}{9}$	$\frac{1}{10}$	$\frac{1}{11}$	$\frac{1}{12}$	$\frac{1}{13}$	$\frac{1}{14}$	$\frac{1}{15}$	$\frac{1}{16}$
S = L×	·75	·875	1	1·125	1·25	1·375	1·5	1·625	1·75	1·875	2

TABLE OF BRIDGES OF LARGE SPAN. ('Trans. Inst. Civ. Eng.,' vol. liv.)

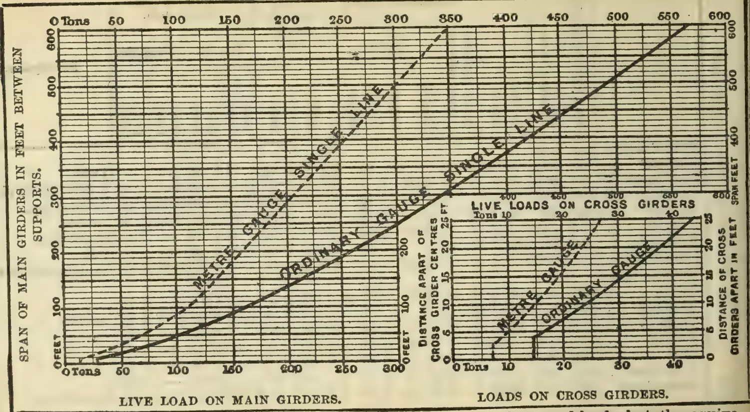
	Span between Bearings.	Weight of Iron.	$\frac{\text{Weight}}{\text{Span}^2}$.	Dimensions in feet.				Loads, tons per lineal foot.		Strains, tons per square inch.				Description.
				Width between Centre Girders.	Panels.					Tensile.		Compress.		
					Number.	Length.	Height.	Live.	Dead.	Dead Load.	Total Load.	Dead Load.	Total Load.	
SINGLE LINE.	feet	tons												
Susquehanna	307	215	·0023	16 0	17	18 2	35 0	0·96	1·00	2·19	4·46	1·96	4·02	Quadrangular; pinned.
Ohio . ..	319	484	·0048	16 6	26	12 3	28 0	1·79	1·34	2·54	4·46	1·38	2·68	Ditto; cast top & struts.
St. Lawrence	330	686	·0063	16 0	—	—	30 0	2·14	1·00	3·43	5·00	2·71	3·97	Tubular.
Elb	328	420	·0039	16 5	20	16 5	32 10	1·28	1·20	—	5·08	—	5·08	
Maas	341	512	·0044	16 8	23	14 7	41 0	1·54	1·00	2·68	4·28	2·68	4·28	Arched top.
Ohio	342	338	·0029	18 0	22	15 6	33 0	1·12	1·34	2·03	4·46	1·62	3·57	Quadrangular; pinned.
Griethausen	342	493	·0042	15 0	40	8 4	25 3	1·52	0·96	—	4·64	—	4·64	
Theiss ..	342	452	·0039	16 5	20	17 0	34 2	1·32	0·95	—	5·08	—	5·08	
Mayence ..	345	359	·0030	15 1	13	25 4	49 2	2·05	1·29	3·18	5·18	—	—	Paule system.
Moerdyk ..	349	447	·0037	16 5	25	14 6	39 8	1·44	1·00	2·25	3·81	2·25	3·81	Arched top.
Louisville ..	368	497	·0037	30 0	24	15 4	46 0	1·64	1·16	3·13	5·36	1·56	2·68	
Kentucky ..	375	425	·0030	18 0	20	18 9	37 6	1·21	0·91	2·27	4·46	2·04	4·02	Quadrangular; pinned.
Louisville ..	396	623	·0040	30 0	28	14 2	46 0	1·86	1·16	3·30	5·36	1·65	2·68	" "
Vistula ..	397	838	·0053	21 8	—	—	28 6	2·75	0·95	3·22	4·34	3·22	4·34	Lattice.

TABLE OF BRIDGES OF LARGE SPAN—*continued.*

	Span between Bearings.	Weight of Iron.	$\frac{\text{Weight}}{\text{Span}^2}$.	Dimensions in feet. Width of Girders apart, centres.	Panels. Number.	Panels. Length.	Height.	Loads, tons per lineal foot. Live.	Loads, tons per lineal foot. Dead.	Stress, tons per square inch. Tensile. Dead Load.	Tensile. Live Load.	Compress. Dead Load.	Compress. Live Load.	Description.
SINGLE LINE.	feet	tons												
Conway ..	400	1112	·0070	15 0	—	—	25 6	2·88	1·00	4·11	5·54	—	—	Tube.
Cincinnati ..	415	830	·0048	19 0	20	20 9	41 6	2·45	2·01	2·45	4·46	2·21	4·02	Quadrangular; pinned.
Waal	408	860	·0052	17 2	27	14 11	42 7	1·97	0·86	2·85	4·13	2·84	4·44	Arched top.
Passaw ..	420	327	·0019	15 0	23	14 0	27 0	0·94	0·99	2·99	6·12	2·63	5·36	Lattice.
Saltash ..	455	945	·0046	17 0	12	38 0	60 0	2·90	1·00	2·97	4·00	—	—	Lenticular.
Britannia ..	460	1553	·0073	15 0	—	—	30 0	3·47	1·00	4·63	5·95	—	—	Tube.
Cincinnati ..	515	1176	·0044	20 0	20	25 9	51 5	2·41	0·81	3·33	4·46	2·95	4·02	Quadrangular; pinned.
DOUBLE LINE.														
Zeglin.. ..	302	449	·0049	27 3	17	19 8	45 11	1·49	1·79	—	4·76	—	4·76	
Runcorn ..	305	702	·0075	28 0	—	—	27 0	2·52	1·50	2·95	4·65	2·18	3·48	Lattice.
Tilsit	317	604	·0060	28 10	18	17 7	39 0	2·10	2·28	—	4·76	—	4·76	
Vistula ..	319	605	·0059	37 9	18	18 3	46 2	1·90	2·16	—	4·64	—	4·64	
Elb	338	592	·0052	27 3	20	17 8	49 3	1·92	2·16	—	4·76	—	4·76	
Dusseldorf..	347	659	·0055	28 0	27	12 4	44 5	1·89	1·91	—	4·64	—	4·64	
Kuilenberg	492	2234	·0092	30 4	38	13 1	65 7	5·89	1·34	5·27	6·50	3·66	4·46	Arched top.

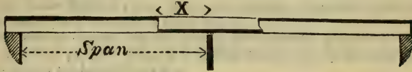
M

DIAGRAM OF LIVE LOADS ON GIRDER BRIDGES FOR A SINGLE LINE OF RAILWAY, LOAD EQUALLY DISTRIBUTED, IN TONS.



Note.—The loads indicated in the diagrams are not necessarily the actual loads, but the equivalent to that of a distributed load which would produce nearly the same result; for example, 14 tons concentrated on the centre is taken as 28 distributed. The loads on cross girders are the actual loads.

CONTINUITY OF GIRDERS.



$X =$ Distance of point of contrary flexure from pier.
$S =$ Span. $L =$ Load on one span.
$l =$ Load on the other span.

Where $L = l$, $X = \frac{1}{4}$ span $= \frac{S}{4}$.

Where L is greater than l,

$$X = S - \left(\frac{7L - l}{8L} S\right).$$

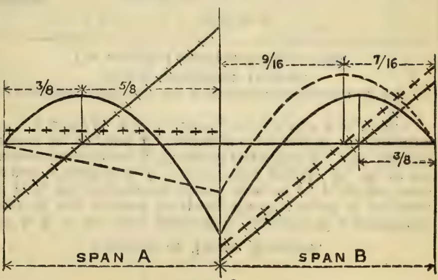
Pressure on centre pier $= \frac{5}{8} S (L + l)$.

" abutments $= S\left(\frac{7L - l}{16}\right)$.

The thick lines representing the top and bottom flanges are in compression. The fine lines are in tension.

CONTINUOUS UNIFORM BEAM OF TWO EQUAL SPANS.
DIAGRAM OF BENDING MOMENTS AND SHEARING FORCES
(uniform loading).

——— denotes bending moments, A and B uniformly loaded.
-+-+-+- " shearing forces " "
— — — " bending moments, A unloaded, B loaded.
+ + + " shearing forces " "



Theorem of Three Moments.

If A, B, C, be three consecutive supports of a continuous girder of any number of spans, whether equal or unequal, and l_1 l_2 the consecutive spans; then let p_1 p_2 = the loads per unit of span on l_1 l_2 respectively; and M_1 M_2 M_3 = the bending moments on A, B, and C respectively. The relation between M_1 M_2 and M_3 is always expressed by the equation $M_1 \cdot l_1 + 2\,M_2 \cdot (l_1 + l_2) + M_3 \cdot l_2 = \frac{1}{4}(p_1 \cdot l_1^3 + p_2 \cdot l_2^3)$.

Load on the Supports of a Continuous Girder of Equal Spans uniformly loaded.

The weight of one Span being = 1·00.

Number of Spans.	Load on the							
	Abutment.	1st Pier.	2nd Pier.	3rd Pier.	4th Pier.	5th Pier.	6th Pier.	7th Pier.
2	$\frac{3}{8}$	$\frac{10}{8}$	—	—	—	—	—	—
3	$\frac{4}{10}$	$\frac{11}{10}$	—	—	—	—	—	—
4	$\frac{11}{28}$	$\frac{32}{28}$	$\frac{26}{28}$	—	—	—	—	—
5	$\frac{15}{38}$	$\frac{43}{38}$	$\frac{37}{38}$	—	—	—	—	—
Infinite	·3943	1·134	·9641	1·0096	·9974	1·0007	·9998	1·00

When the number of spans exceeds *five*, the loads on the supports are nearly the same as when the number is infinite.

Deflection of Wrought-iron Girders.

Deflection of $\frac{1}{400}$ to $\frac{1}{600}$ of the length may be allowed under special circumstances; but under ordinary loads the deflection should not exceed $\frac{1}{4}$ of these, say $\frac{1}{1600}$ to $\frac{1}{2400}$.

The practice in America is to allow $\frac{1}{1200}$ after the girder has taken its permanent set.

In small bridges there is a slight increase in deflection from high speeds, about $\frac{1}{6}$th or $\frac{1}{7}$th of the normal deflection, with the same load moving at slow speed.

In large girders there is no perceptible difference between the deflection at high and low speeds.

Deflection of Iron and Steel Girders, Ends Supported.

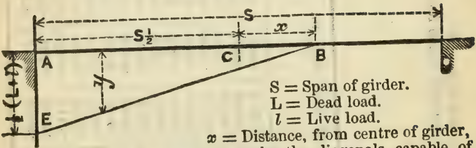
S = Span in feet.
P = Stress on the metal by any load in tons per square inch.
E = Modulus of elasticity in tons = say 10,000 for iron and 13,000 for steel.
D = Effective depth of girder in feet.
d = Deflection of girder in inches.

$$d = \frac{3\,S^2\,P}{E\,D} = S\,K.$$

Table of Values of K.

Material.	Stress, tons per sq. inch.		Ratio of Effective Depth of Girder to Span.								
			$\frac{1}{8}$	$\frac{1}{9}$	$\frac{1}{10}$	$\frac{1}{11}$	$\frac{1}{12}$	$\frac{1}{13}$	$\frac{1}{14}$	$\frac{1}{15}$	$\frac{1}{16}$
Iron	½	K =	·0012	·0014	·0015	·0017	·0018	·0020	·0021	·0023	·0024
"	1	K =	·0024	·0027	·0030	·0033	·0036	·0039	·0042	·0045	·0048
"	2	K =	·0048	·0054	·0060	·0066	·0072	·0078	·0084	·0090	·0096
"	3	K =	·0072	·0081	·0090	·0099	·0108	·0117	·0126	·0135	·0144
"	4	K =	·0096	·0108	·0120	·0132	·0144	·0156	·0168	·0180	·0192
"	5	K =	·0120	·0135	·0150	·0165	·0180	·0195	·0210	·0225	·0240
Steel	½	K =	·0009	·0010	·0012	·0013	·0014	·0015	·0016	·0017	·0018
"	1	K =	·0018	·0021	·0023	·0025	·0028	·0030	·0032	·0035	·0037
"	2	K =	·0037	·0041	·0046	·0051	·0056	·0060	·0064	·0069	·0074
"	3	K =	·0055	·0062	·0069	·0076	·0083	·0090	·0097	·0104	·0110
"	4	K =	·0074	·0083	·0092	·0101	·0110	·0120	·0129	·0138	·0147
"	5	K =	·0092	·0104	·0115	·0127	·0138	·0150	·0161	·0173	·0184
"	6	K =	·0110	·0124	·0138	·0152	·0166	·0179	·0193	·0207	·0221
"	7	K =	·0129	·0145	·0161	·0177	·0193	·0209	·0225	·0242	·0258
"	8	K =	·0147	·0166	·0184	·0202	·0221	·0239	·0258	·0276	·0294

Counter-bracing Girders.



S = Span of girder.
L = Dead load.
l = Live load.
x = Distance, from centre of girder, to which it is necessary to make the diagonals capable of resisting both compression and tension.

$$R = \frac{L}{l}\,.$$

$$x = \tfrac{1}{2}S - S\left(\sqrt{R + R^2} - R\right) = Sk.$$

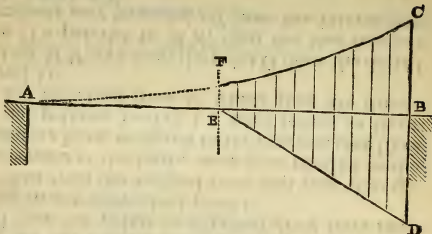
Values of k or coefficient of distance from centre of girder to which it is necessary to counterbrace).

Dead load. / Live load.	2·5	2·4	2·3	2·2	2·1	2·0	1·9	1·8	1·7	1·6
k	·042	·043	·045	·047	·049	·051	·053	·055	·058	·060
Dead load. / Live load.	1·5	1·4	1·3	1·2	1·1	1·0	·9	·8	·7	·6
k	·064	·067	·071	·075	·080	·086	·092	·10	·109	·12
Dead load. / Live load.	·5	·4	·35	·3	·25	·2	·15	·1	·08	·05
k	·134	·152	·164	·186	·193	·210	·237	·268	·284	·321

With any scale lay off $AE = \frac{1}{2}(L + l)$; join EB; then the vertical ordinate y at any point between A and C measures the maximum shearing force that can exist at that point from unequal loading.

STRAINS ON LATTICES.

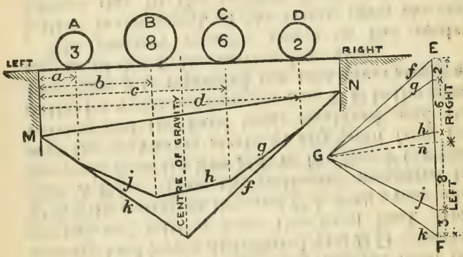
With a distributed load advancing from either point of support.



Let the line A B represent the span; E being the centre. With any convenient scale lay off B C = the strain on the end lattices from the moving load *evenly* distributed, and B D = strain on the end lattices from the fixed load. Join D E with a straight line and C A with a parabolic line A F C. Then the ordinates measured by the scale from the line D E to the line F C represent the maximum strain at any point from the moving and the fixed loads combined, and the ordinates measured from the line B E to the parabolic line F C represent the maximum strain at any point due to the moving load alone.

The greatest possible strain on the centre lattices is one-fourth of the strain upon the end lattices due to the moving load alone *evenly distributed.*

Distribution of Load on Abutments.



Form a polygon of forces as follows:—

With any convenient scale on the vertical line E F set out lengths corresponding to the loads, and from the points so obtained draw lines radiating to any convenient point G.

Then from the vertical lines that pass through the centres of the loads, draw lines parallel to the radiating lines, as shown in the diagram (the lines of the polygon having the same letters as those of the radiating lines to which they are drawn parallel).

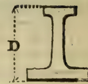
Join M N, and from the point G draw the dotted line G n parallel to M N, then the load on each abutment may be scaled off from the intersection of G n with E F.

By calculation, the load on the right abutment

$$= \frac{A\,a + B\,b + C\,c + D\,d}{\text{Span}}.$$

Load on left = total load − load on right.

Cast-iron Girders.



D = Depth of girder in inches.
A = Area of bottom flange in inches.
S = Span in inches.
W = Breaking weight in tons.

Supported at both ends with load on centre .. .. $W = \dfrac{25\,A\,D}{S}$

Supported at both ends with load distributed .. .. $W = \dfrac{50\,A\,D}{S}$

If the depth $= \frac{1}{12}$ of the span, $W = A\,4 \cdot 17$
If the depth $= \frac{1}{10}$ of the span, $W = A \times 5$ } where weight is distributed

Area of top flange if the load is applied on the top .. .. .. $= \dfrac{A}{3}$

Area of top flange if the load is applied on bottom flange .. $= \dfrac{A}{2}$

Depth at the ends may equal $\dfrac{2\,D}{3}$

Safe deflection $\frac{1}{40}$th inch for each foot of span, under a test load of $\frac{1}{3}$rd of the breaking weight.

Breaking Weight of Cast-iron Girders.

(In tons distributed.)

Span in feet.	Depth in inches.	Size of bot. flange.	Breaking weight.	Size of bot. flange.	Breaking weight.
10	10	$6 \times 1\frac{1}{4}$ =	31	$8 \times 1\frac{1}{4}$ =	41
15	15	$8 \times 1\frac{1}{2}$ =	50	$12 \times 1\frac{1}{2}$ =	75
20	20	$10 \times 1\frac{1}{2}$ =	62	$15 \times 1\frac{1}{2}$ =	94
25	25	$13 \times 1\frac{3}{4}$ =	94	19×2 =	158
30	30	15×2 =	125	22×2 =	183
35	35	17×2 =	141	25×2 =	208

Wrought-iron Plate Girders.

L = Length of girder (or span) in feet.
W = Weight distributed in tons.
D = Effective depth of girder in feet.
S = Strain on top and bottom flange at centre [in tons.

$$S = \frac{W L}{8 D}.$$

If the depth $= \frac{L}{8}$, then $S = W$.

" " $= \frac{L}{10}$, " $S = 1\frac{1}{4} W$.

" " $= \frac{L}{12}$, " $S = 1\frac{1}{2} W$.

In compression, iron may be strained to 4 tons per square inch.

In tension, iron may be strained to 5 tons per square inch.

By Board of Trade regulations, 5 tons per square inch in tension and compression.

By regulations of the Ponts et Chaussées, 3·81 tons per square inch.

Safe Limit of Stress in Wrought-iron Bridges.

With different proportions of Dead to Live load.

S = Safe limit in tons per square inch.
Dead load + live load = 1·0.

Unwin.

Live load ..	0	·1	·2	·3	·4	·5	·6	·7	·8	·9	1·0
Dead load ..	1·0	·9	·8	·7	·6	·5	·4	·3	·2	·1	0
S. in tension =	7·0	6·36	5·83	5·38	5·0	4·66	4·37	4·12	3·87	3·68	3·5
S. in compn. =	5·6	5·09	4·66	4·31	4·0	3·73	3·50	3·29	3·11	2·85	2·8

Thickness of Web Plates of Wrought-iron Girder to resist Diagonal Force. (Chas. Light.)

The tabular numbers show safe thrust in tons per foot of width of plate.

Thickness of Web, ins.	Net unsupported Distances in inches whether between Pillars or Booms.									
	24	27	30	33	36	39	42	45	48	51
$\frac{1}{4}$	1·5	1·2	1·0	·8	·7	·6	·5	·45	·4	·36
$\frac{5}{16}$	2·8	2·2	1·8	1·5	1·3	1·2	1·0	·9	·8	·7
$\frac{3}{8}$	4·3	3·5	3·0	2·6	2·2	1·9	1·7	1·5	1·3	1·2
$\frac{7}{16}$	6·3	5·3	4·5	3·9	3·4	2·9	2·6	2·3	2·0	1·8
$\frac{1}{2}$	8·7	7·4	6·3	5·5	4·8	4·2	3·7	3·3	3·0	2·7
$\frac{9}{16}$	11·2	9·8	8·5	7·4	6·5	5·7	5·1	4·6	4·2	3·8
$\frac{5}{8}$	14·0	12·3	10·8	9·5	8·4	7·5	6·7	6·0	5·4	4·9
$\frac{11}{16}$	17·0	15·0	13·4	11·9	10·6	9·5	8·5	7·6	6·8	6·3
$\frac{3}{4}$	20·0	17·9	16·1	14·5	13·0	11·7	10·5	9·5	8·6	7·8

The tabular number under the distance required must not be less than the shearing force per foot of plate.

Lattice Bridges.

See 'Min. Inst. Civ. Eng.,' vol. xi. (W. T. Doyne.)

W = Weight distributed.
S = Strain at centre of top and bottom flanges.
x = Distance of any point from abutment.
y = Strain on any lattice.
a = Distance of centre of any lattice from centre of girder.
l = Length of any lattice.
L = Length of bearing of girder or span.
D = Depth of girder (effective).

$\frac{W L}{8 D} = S$ at centre; $\frac{W}{2 D L}(L x - x^2) = S$, at any point whose distance is x from abutment.

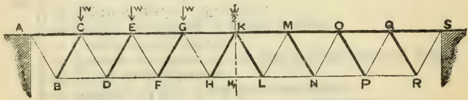
$y = W \frac{a l}{D L}$; y is for single triangulation, and must be divided by the number of series of triangulation.

If w = weight applied at centre of girder, $\frac{w l}{2 D}$ = strain on all the lattices.

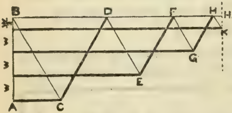
STRESS DIAGRAMS FOR BRACED GIRDERS. (Dewar.)

On the vertical line A Y set off, with any scale, the units of load at each apex (= in this case $\frac{1}{8}$ total load evenly distributed). Draw, from each point thus set off, lines parallel to the top and bottom booms; and diagonal lines parallel to the bracing. The stresses may be measured off by the scale of units.

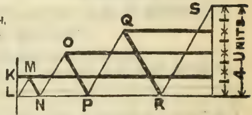
GIRDER DIAGRAM. LOAD DISTRIBUTED.



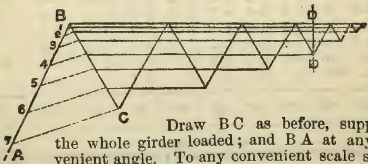
STRESS DIAGRAM.



STRESS DIAGRAM.
Alternative Load.



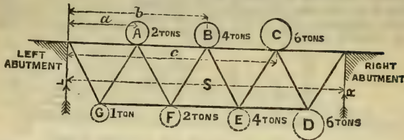
MAXIMUM STRESS ON EACH DIAGONAL FROM A PARTIAL TRAVELLING LOAD UNIFORMLY DISTRIBUTED. (Dewar.)



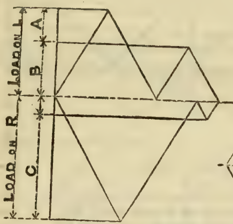
Draw B C as before, supposing the whole girder loaded; and B A at any convenient angle. To any convenient scale set out B 1 = 1; 1, 2 = 2; 2, 3 = 3; 3, 4 = 4, ending at 6, 7 = 7, the number of loaded apices in the girder. Join 7 C and draw lines parallel to it through 6, 5, 4, &c., cutting B C, and through the points of intersection draw horizontal lines and zigzag lines parallel to the diagonals as before. The diagonals represent the greatest stress from a travelling load. Beyond the centre D they represent the greatest compression on what would be a tie if the load were fixed, and tension on what would be a strut.

Girders Unequally Loaded.
(Graphic Determination of Stresses.)

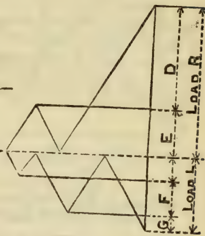
DIAGRAM OF LOAD.



STRESS DIAGRAM FOR LOADS A, B, AND C.



STRESS DIAGRAM FOR LOADS D, E, F, AND G.



Find the load on each abutment as follows:
With loads A, B, and C, the load on the right abutment

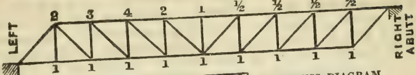
$$R = \frac{a\,A + b\,B + c\,C}{S},$$

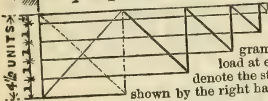
and on the left abutment $L = (A + B + C) - R$.

On a vertical line with any convenient scale lay off distances corresponding to the loads on each point of the girder and on each abutment, and draw lines parallel to each member of the girder; the diagonal lines being drawn to the horizontal line corresponding to the division of load on the abutments. The stresses may then be measured on the Stress Dia grams with the scale of loads. If the girder be turned upside down, the stresses will remain the same in intensity, but their character will be changed, the positive stresses becoming negative, and the negative positive.

STRESSES ON BRACED GIRDERS. (Graphic Construction.)

DIAGRAM OF LOAD.

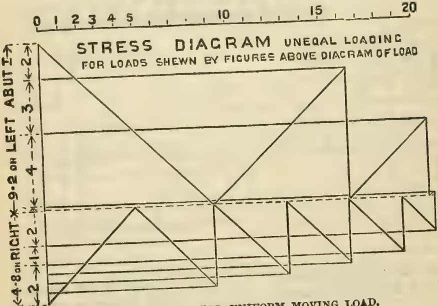




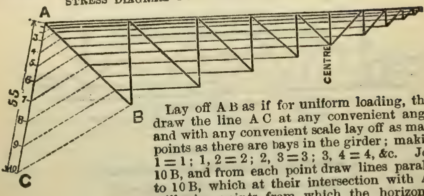
STRESS DIAGRAM FOR UNIFORM LOADS.

The figures below the diagram of load denote the units of load at each point. The dotted lines denote the stresses on a girder of the form shown by the right half of the diagram of load.

SCALE OF UNITS OF LOAD.



STRESS DIAGRAM FOR UNIFORM MOVING LOAD.



Lay off A B as if for uniform loading, then draw the line A C at any convenient angle, and with any convenient scale lay off as many points as there are bays in the girder; making $1 = 1$; $1, 2 = 2$; $2, 3 = 3$; $3, 4 = 4$, &c. Join 10 B, and from each point draw lines parallel to 10 B, which at their intersection with A B will give points from which the horizontal lines of the stress diagram may be drawn.

Strains on Girders.

See 'Min. Inst. Civ. Eng.,' vol. xxiv. (C. Reilly.)

The figures on the diagrams show the respective strains in terms of the load.

The load distributed being taken as 100.

The proportions adopted to give these strains are—

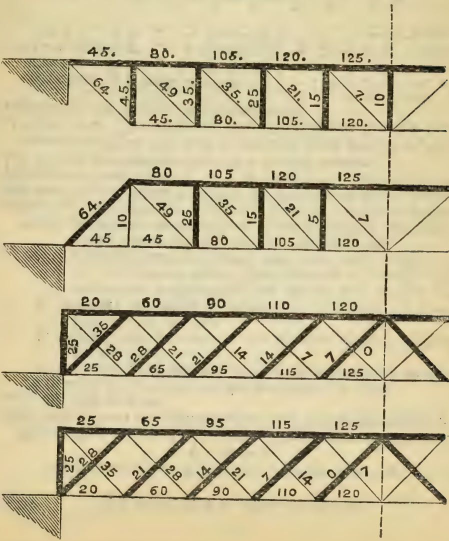
Depth of girder $= \frac{1}{10}$ of span.

Angle of bars $= 45^\circ$.

Girder divided into ten equal bays, each $= \frac{1}{10}$ span.

Thick lines are in compression; thin lines in tension.

In diagrams 1 and 3 the load is applied at the top; in 2 and 4 at the bottom of the girder. The load is distributed evenly, but in cases of unequal loading the bars change their character and strains.



Calculation of Stress on Braced Girders.

(C. Lean.)

The coefficients are obtained by writing down the effect of each unit of load on each member, and taking the totals + or − for each member.

To find the actual stress on the members of a girder:

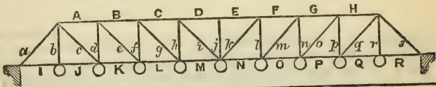
1. Find the total amount of dead and live load on the girder.
2. Divide these amounts by the number of bays to find the unit for one bay.
3. Multiply the units of dead and live loads by their respective coefficients, and divide the results by the number of bays. The quotient represents the greatest possible stress that can come upon the girder under any conditions of the live load.

For diagonals the amount must be multiplied by the length of the bar divided by the depth of the girder; if the length of the bay does not equal its depth the amount must be multiplied by the length and divided by the depth. The results for the flanges must be corrected in a similar manner.

Example.—With live load = 100 tons, dead load = 50, find stresses on k. (See diagram below.) Units = 10 and 5 tons respectively in tension and compression.

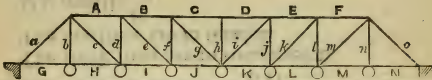
$$\left.\begin{array}{l}\text{Live load } 10 \times \text{coef.} -15 = 150 \\ \text{Dead } ,, \quad 5 \times \;,, \; -5 = 25\end{array}\right\} -175 \div \overset{\text{bays.}}{10} \times \overset{\text{length.}}{1{\cdot}41} = -24{\cdot}75 \text{ tons.}$$

$$\left.\begin{array}{l}\text{Or Live load } 10 \times \;,, \; +10 = +100 \\ ,, \text{ Dead } ,, \quad 5 \times \;,, \; -5 = -25\end{array}\right\} + 75 \div 10 \times 1{\cdot}41 = +10{\cdot}6 \text{ tons.}$$

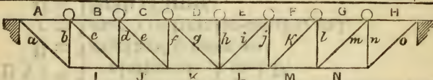


	a & s		b & r		c & q		d & p		e & o		f & n		g & m		h & l		i & k	
	+	−	+	−	+	−	+	−	+	−	+	−	+		+	−	+	−
Coefficient live load	45			10	1	36	28	3	3	28	21	6	6	21	15	10	10	15
,, dead ,,	+45		−10		−35		+25		−25		+15		−15		+5		−5	
	A & H		B & G		C & F		D & E		I & R		J & Q		K & P		L & O		M & N	
Coef. booms	+80		+105		+120		+125		−45		−45		−80		−105		−120	

LEAN'S STRESSES.



	a & o		b & n		c & m		d & l		e & k		f & j		g & i		h	
	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−
Coefficient live load	28			8	1	21	15	3	3	15	10	6	6	10	0	0
Coef. dead load	+28		−8		−20		+12		−12		+4		−4		0	
	A & F		B & E		C & D		G & N		H & M		I & L		J & K			
Coefficient booms	+48		+60		+64		−28		−28		−48		−60			



	a & o		b & n		c & m		d & l		e & k		f & j		g & i		h	
	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−
Coefficient live load		28	28		1	21	21	1	3	15	15	3	6	10	8	
Coef. dead load	−28		+28		−20		+20		−12		+12		−4		+8	
	A & H		B & G		C & F		D & E		I & H		J & M		K & L			
Coefficient booms	+28		+48		+60		+64		−28		−48		−60			

BOWSTRING BRIDGES.

T = Tension of main tie, and
  = Thrust of arch at crown, in tons.
S = Span „ „ in feet
R = Rise „ „ „
L = Total load distributed in tons.
x = Distance of any part from centre of girder in feet.

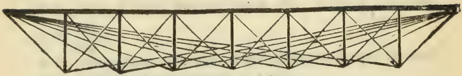
$$T = \frac{L\,S}{8\,R}.$$

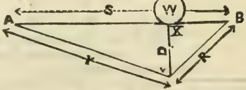
Thrust at any other part of arc $= \sqrt{T^2 + \left(\frac{L}{S}\right)^2 \cdot x^2}$.

Greatest tension at any perpendicular $= \frac{L}{N}$ nearly, when

N = number of parts into which the arc is divided by the perpendiculars.

American Truss Bridge.





L = Total load distributed.
N = Number of panels or bays.

$W = \frac{L}{N}$ = Load at each point of suspension.

S = Span.

$\left.\begin{matrix} A\,X \\ B\,X \end{matrix}\right\} = \left\{\begin{matrix} \text{Distance of any point of suspension from} \\ \text{abutments A and B.} \end{matrix}\right.$

R = Length of tension rod.
r = Length of counter-tension rod.
D = Depth of truss.

Strain on tension rod $R = \frac{W.A\,X}{S} \times \frac{R}{D}$.

Strain on counter-tension $r = \frac{W.B\,X}{S} \times \frac{r}{D}$.

Strain of perpendicular strut = W.

Strain on top at centre $= \frac{S\,L}{8\,D}$.

The thick lines are in compression.
The fine lines are in tension.

D is usually $\frac{S}{7}$.

[*For continuation see next page.*]

American Truss Bridge—*continued.*

The strain on top at centre $= \frac{S\,L}{8\,D}$, is on the supposition that the diagonal bracing shown in the diagram is used, and that they are fixed to each other at the points of intersection. When the girder consists of a number of separate triangles unconnected except by the top boom, the strain on the top boom will be uniform throughout, and $= \frac{L\,S}{D} \cdot \frac{N^2 - 1}{6\,N^2}$

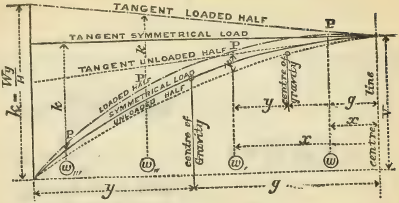
Iron Arches

T = Strain at centre of arch.
t = Strain at any point x.
L = Total load on arch.
l = Load between centre of arch and x.
V = Versed sine.
S = Span of arch.

$$T = \frac{L\,S}{8\,V}. \qquad t = \sqrt{T^2 + l^2}$$

$$V = \frac{S}{10} \text{ generally.}$$

Arches. (Equilibrium line.)



V = Versed sine of arch.

x = Abscissa measured horizontally from crown centre line to any point P.

w = Weight of arch and load supposed to be concentrated at any point P.

W = Sum of weights between crown and any point P. $= w + w_1 +$ &c.

m = Moments at each point P $= w\,x$.

M = Sum of moments between crown and P $= m + m_1 +$ &c.

g = Horizontal distance of centre of gravity (of portion of arch between crown and P) measured from crown $= \frac{M}{W}$

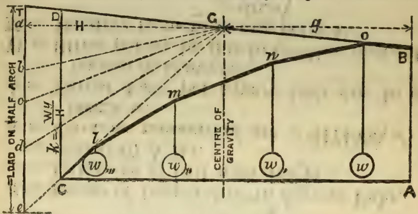
y = Ditto ditto measured from P $= x - g$.

H = Horizontal thrust of arch $= \frac{W\,y}{V}$ for symmetrical loads; $= \frac{W\,y + W'\,y'}{2\,V}$ for unsymmetrical loads; when Wy and W$'y'$ are for the loaded and unloaded halves respectively.

k = Ordinate from tangent to line of equilibrium. The tangent will be horizontal for symmetrical loads and inclined for unsymmetrical loads. Obliquity determined by the formula $\frac{W\,y}{\ }$ $k = \frac{W\,y}{\ }$.

BRACED ARCHES.

Determination of Equilibrium Line by Graphic Construction.



For notation see preceding page.

1st. Lay off from crown of arch tangent B D, making $k = \dfrac{W\,y}{H}$.

2nd. Find position of centre of gravity; $g = \dfrac{M}{W}$.

3rd. From G (the point of intersection of the vertical line passing through the centre of gravity) draw the horizontal line G a = H, to any convenient scale.

4th. Through a draw the vertical line T $a\,e$, making T e = total load on half arch = W.

5th. On the line T e lay off T b, $b\,c$, $c\,d$, $d\,e$ $w\ w_{,}\ w_{,,}\ w_{,,,}$ respectively.

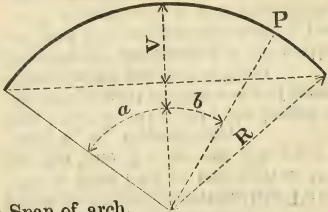
6th. Join b G, c G, d G, e G; the length of these lines represent the intensity of stress on the lines drawn parallel to them.

7th. Draw to the intersection of the vertical lines of load B o, $o\,n$, $n\,m$, $m\,l$, and $l\,e$, parallel to G T, G b, G c, G d, G e, respectively commenced at B.

The line $l\,e$ should pass through the point C; this checks the accuracy of calculation and drawing.

Iron Arches. (Strains due to expansion.)

Dimensions to be all in inches.



S = Span of arch.
V = Versed sine.
R = Radius of arch $= \dfrac{V^2 + (\frac{1}{2} S)^2}{2 V}$.

a = Angle of half arch; = Sin. $a = \dfrac{S}{2 R}$.
b = Angle of P with centre line.
d = Effective depth of arched rib from centre to centre of top and bottom booms of rib.
E = Modulus of elasticity = 11,000 tons for iron.
= 12,800 tons for steel.

K = Constant for rib, say $\dfrac{E d^2}{2}$.

t = Range of temperature in degrees Fahr.
e = Extension of half arch due to t.
= ·00000667 A R t.
A = Circular measure of arc = ·0174533, a° = 00029, a'.
h = Thrust force per square inch due to extension at abutment.
H = Stress per sq. in. due to bending moment.
M = Bending moment at any point P.

$$h = \frac{K}{R^3} \times \frac{\left(\dfrac{e \sin. a}{A}\right)}{A(\cdot 5 \sin.^2 a + 1 \cdot 5 \cos.^2 a) - 1 \cdot 5 \sin. a \cos. a}$$

$H = \dfrac{M}{z}$; $M = h V (\cos. b - \cos. a)$.

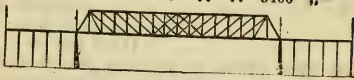
Bridges of Large Span.

('Min. Inst. Civ. Eng.,' vol. liv. Clarke.)
Comparative Weights of different Types.
Span 700 feet clear.
With 250 feet of viaduct at each end.

Double line of railway; live load 3400 lbs. per foot; wind pressure, 40 lbs. per square foot; iron strained to 10,000 lbs. per square inch (say 4·46 tons).

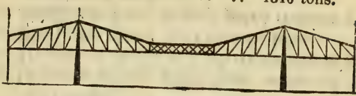
STRAIGHT GIRDER.

715 feet main girder	4900 tons.
500 feet viaduct	500 "
Total	5400 "



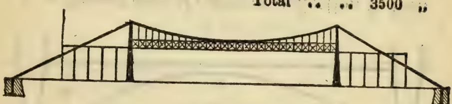
CANTILEVERS WITH CONNECTING SPAN.

1215 feet of cantilever .. .. 4340 tons.



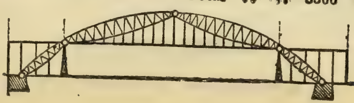
STIFFENED SUSPENSION BRIDGE.

715 feet of suspension girder and back chains	3000 tons.
500 " viaduct	500 "
Total	3500 "

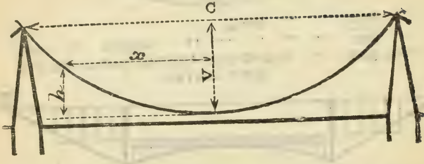


BRACED ARCH.

715 feet of arch and shore abutments ..	2800 tons.
500 " viaduct	500 "
Total	3300 "



Suspension Bridges.



V = Versed sine of curve or deflection in feet.
C = Chord or span in feet.
L = Load in tons distributed, including weight of bridge.
x = Distance of any point from centre of curve.
h = Height of chain at x above centre of chain.
S = Strain on chain in centre in tons.
s' = Strain on ditto, at any point distant x from centre of span.
N = Number of tension rods.
A = Angle of tangent of chain with horizon at any point x.

$$h = \frac{V \times x^2}{(\frac{1}{2}C)^2}. \qquad \text{Tan } A = \frac{4V}{C}$$

$$S = \frac{CL}{8V}.$$

$$s' = S\sqrt{\left(\frac{2h}{x}\right)^2 + 1} = S, \text{ secant } A.$$

$$V = \frac{C}{13} \text{ generally.} \quad V = \sqrt{[(\tfrac{1}{2}l)^2 - (\tfrac{1}{2}C)^2]} \times \cdot 75.$$

$$\text{Strain on any tension rod} = \frac{L}{N-1}.$$

$$l = \text{Length of chain} = 2\sqrt{(\tfrac{1}{2}C)^2 + \tfrac{4}{3}V^2}.$$

Stiffened Suspension Bridges.

STRESSES IN STIFFENING GIRDERS.

(Major Allan Cunningham, R.E.)

Calculations based on Rankine's hypothesis that the effect of the stiffening girder is to distribute a partial uniform load uniformly all over the chain.

w = Weight of moving load in tons per foot run.
c = Half span.
x and x_1 = Variable abscissæ of any point in the span measured from A and A_1 respectively.
y = Ditto measured from the centre.
M = Greatest bending moment under moving load.
F = Greatest shearing force " "

DIAGRAM OF BENDING MOMENTS.

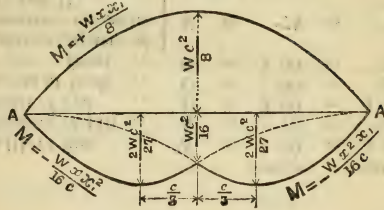
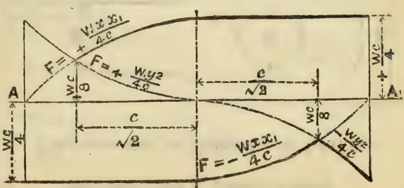
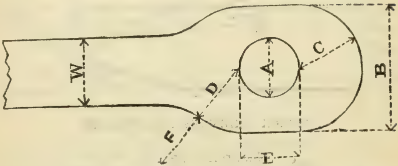


DIAGRAM OF SHEARING FORCES.



Proportions of Suspension Links.



			Berkley's.		Saltash.
Width of link ..	W	=	1·00	=	1·00
Diameter of pin ..	A	=	·75	=	·66
Width of eye ..	B	=	2·00	=	1·87
Radius of back ..	C	=	1·00	=	·935
" front ..	D	=	1·00	=	·935
Distance apart of centres for radii C and D	E	=	·75	=	·1
Radius of shoulder	F	=	1·5	=	7·6

Iron Pins in Suspension Bridges or Girders.

The bearing surface of pins should be so proportioned that the working pressure will not exceed $3\frac{1}{2}$ or 4 tons per square inch.

D = Diameter of pin in inches; minimum value of D = ·75 W (Berkley), or ·66 W (Fox).
t = Thickness of link in inches.
W = Width of link in inches.
d = Diameter of link in inches (if round).

$$D = 1{\cdot}8\,t\sqrt[3]{\frac{W}{t}};\ \text{or} = 1{\cdot}1\sqrt[3]{4\,d^3 - \tfrac{1}{4}\,d^2} = 1{\cdot}8\,t \text{ for}$$

square links.

If D, as determined above, be less than the minimum, it must be increased to the minimum.

RAILWAYS.

PARLIAMENTARY REGULATIONS FOR RAILWAYS CROSSING ROADS.

	Turnpike road.	Public road.	Occupation road.
	ft. in.	ft. in.	ft. in.
Clear width of under bridge, or approach	35 0	25 0	12 0
Clear height of under bridge for a width of 12 feet ..	16 0	—	—
Ditto, for a width of 10 feet	..	15 0	—
Ditto, " " 9 "	..	..	14 0
Ditto, at springing	12 0	12 0	—
Over bridge. Height of parapets	4 0	4 0	4 0
Approaches. Inclination .	1 in 30	1 in 20	1 in 16
Ditto. Height of fencing .	3 0	3 0	3 0

LIMITS OF DEVIATION.

In towns, 10 yards each side of centre line.
In the country, 100 yards, or 5 chains nearly.

DEVIATIONS OF LEVEL.

In towns, 2 feet. In the country, 5 feet.

DEVIATIONS OF GRADIENT.

Gradients flatter than 1 in 100, deviation 10 feet per mile steeper.

Ditto, steeper, 3 feet per mile steeper.

DEVIATIONS OF CURVE.

Curves upwards of ½ a mile radius, may be sharpened to ½ mile radius.

Curves of less than ½ mile radius may not be sharpened.

SCALES FOR PLANS DEPOSITED UNDER STANDING ORDERS.

Minimum scale for plans and sections	= 4 inches to the mile.
Ditto, vertical ditto, for sections	= 100 feet to the inch.
Minimum scale for enlarged plans of buildings, &c.	= 6 chains to the inch.
Minimum scale for cross-sections, and sections of road alterations ..	= 40 feet to the inch.

Board of Trade Regulations for Railways.

MAIN LINE.

Breaking weight of cast-iron girders to be made = permanent load × 3 + moving load × 6.

Wrought-iron bridges must not be strained to more than 5 tons per square inch when loaded with the heaviest engines.

Minimum distance of standing work from the outer edge of rail at level of carriage steps.
= 3 feet 6 inches in England.
= 4 feet in Ireland.

Minimum distance between lines of railways = 6 feet.

STATIONS.

Minimum width of platform = 6 feet; 12 feet at important stations.

Minimum distance of column from edge of platform = 6 feet.

Steepest gradient recommended for stations = 1 in 260.

Board of Trade Regulations—*continued.*

CARRIAGES.

Minimum space per passenger = 20 cubic feet.
Minimum area of glass per passenger = 60 superficial inches.
Minimum width of seats = 15 inches.
Minimum breadth of seat per passenger = 18 in.
Minimum number of lamps per carriage = 2.

PERMANENT WAY.

Joints of rails to be fished.
Chairs to be secured by *iron* spikes.
Fang bolts to be used at the joints of flat-bottomed rails, and at some intermediate places.

STATIONS.

Ends of platforms to be ramped (not *stepped*).
Signals and distant signals in both directions.
Signals to be weighted to fly to "danger" if wire breaks.
Switch handles to be brought together.
" " not to be worked between lines of rail.
Facing points to be avoided.
" " where unavoidable, to be furnished with self-acting signal.
Sidings to be supplied with locked chock-block.
Sidings on a gradient falling towards the line to be provided with a blind siding.
Turn-tables to be a safe distance from adjacent lines.
Platforms of bridges protected from fire.
Walls and handrails to be provided on viaducts at stations.

BOARD OF TRADE REGULATIONS—*continued.*

STATIONS—*continued.*

Level-crossing gates to be capable of being closed across both road and railway.

Clocks visible at all stations.

Mile posts and gradient boards.

Tunnels and dangerous places protected by telegraph.

Tunnels provided with man-holes.

PRECAUTIONS RECOMMENDED IN THE WORKING OF RAILWAYS BY THE BOARD OF TRADE.

1. There should be a break-vehicle with a guard in it at the tail of every train; this vehicle should be provided with a raised roof and extended sides, glazed to the front and back; and it should be the duty of the guard to keep a constant look-out from it along his train.

2. There should be means of intercommunication between a guard at the tail of every passenger train and the engine driver, and between the passengers and the servants of the company.

3. There should be at least one break-vehicle to every three or four carriages in a passenger train, a proportion which may be economically provided by the use of continuous breaks. On steep inclines, and with trains which travel at high speed, a larger proportion of break-power is required.

4. The tires of all wheels should be so secured to the rims of the wheels as to prevent them from flying open when they are fractured.

5. The engines employed with passenger trains should be of a steady description, with not less than six wheels, with a long wheel-base, with the centre of gravity in front of the driving wheels, and with the motions balanced. They should not be run tender first.

6. Records should be carefully kept of the work performed by the wearing parts of the rolling stock, to afford practical information in regard to them, and to prevent them from being retained in use longer than is desirable.

7. When a line is worked by telegraph, the telegraph huts should be commodious, and should be supplied with clocks, with record books, with a separate needle for signalling the trains on each line of rails, and with an extra needle for other necessary communications between the signalmen. The telegraph instruments and signal handles should face the directions in which they work.

8. When drovers or other persons are permitted to travel with goods or cattle trains, suitable vehicles should be provided for their accommodation near the front of such trains.

9. Luggage should not be carried on the roofs of railway carriages.

Regulations for Construction of Prussian Railways and Rolling Stock.

RAILWAY.

Minimum breadth of roadway, double line.. ..	24 ft. 9 in.
Ditto ditto, single line	15 ft. 6 in.
Maximum gradient, level districts	1 in 200
Ditto ditto, hilly ditto	1 in 100
Ditto ditto, mountainous ditto	1 in 40
Minimum radius of curves, flat ditto	3600 feet
Ditto ditto, hilly ditto	1200 feet
Ditto ditto, mountainous ditto	600 feet
Maximum gauge for straight lines and curves of more than 1000 feet radius..	4 ft. $8\frac{1}{4}$ in.
Maximum gauge round sharp curves	4 ft. $9\frac{1}{2}$ in.
Minimum width of top table of rails	$2\frac{1}{4}$ inches
Radius of ditto .. ..from	7″ to 5 in.
Minimum depth of rails	$4\frac{1}{4}$ inches
Inclination of rails inwards	1 in 20
Minimum depth of ballast under sleepers	8 inches

Prussian Railways—*continued.*

LEVEL CROSSINGS AND STATIONS.

Minimum angle of crossing with rails	30°
Minimum width of channel for flange at crossings	$2\frac{5}{8}$ inches
Minimum depth of ditto	$1\frac{1}{2}$ inch
Minimum portion of level at stations, flat districts	1800 feet
Ditto ditto, mountainous ditto ..	600 „
Minimum distance, centre to centre of rail in station	14 „
Minimum radius of crossings and turnouts	600 „
Ditto for facing points at stations for through trains	1000 „
Minimum diameter of engine turn-tables	38 „
Minimum width of passenger plat-forms	18 „
Maximum height —..	18 inches
Minimum distance of pillars in sta-tions from rails	9 ft. 5 in.
Minimum diameter of watercrane pipes	6 inches
Minimum height of fixed portion of watercrane above rails	9 ft. 6 in.

LOCOMOTIVE SHEDS.

Engine pits, in depth, from 2 ft. 6 in. to 3 ft. 6 in.	
Minimum height of water-tanks above rails 17 ft.	
Minimum height of engine doorways	15 ft. 9 in.
Minimum width of ditto	11 feet
Minimum height of the beams from rails	19 „

PRUSSIAN RAILWAYS—*continued.*

CARRIAGE SHEDS.

Minimum distance of rail, centre to centre	14 ft. 6 in.
Minimum height of doorways	13 feet
Minimum width of ditto	11 „

LOCOMOTIVES.

Maximum wheel base of engines with curves 2000 feet radius	15 feet
Ditto, 1500 ditto	13 „
Ditto, 1000 ditto	11 „
Bogie frames should be adopted with curves under 1000 feet rad.	
Maximum load on one axle	$12\frac{1}{2}$ tons
Minimum play of flanges of wheels ..	$\frac{3}{8}$ inch
Minimum clear space between wheels	4 ft. $5\frac{1}{2}$ in
Maximum projection of flange below top of rail	$1\frac{1}{4}$ inch
Maximum width of tire	6 inches
Minimum width of tire	$5\frac{1}{4}$ „
Minimum diameter of driving wheel for goods engine	4 feet
Ditto ditto, for passenger engine ..	5 „
Ditto ditto, for express engine ..	6 „
Minimum diameter of leading and trailing wheel	3 „
Speed of goods train, per hour .. .	16 miles
Passenger ditto, ditto, from 25 to	33 „
Express ditto, ditto	40 „
Maximum pressure in boiler, per sq. in.	100 lbs
Proof pressure in testing boilers ..	150 lbs.
Height of life guards above rails .	2 to $2\frac{1}{2}$ in.
Maximum breadth of engine	10 feet
Ditto height of chimney above rails	15 „

PRUSSIAN RAILWAYS—*continued.*

Minimum diameter of tender wheels	3 feet
Maximum breadth of tender	9 "
Ditto height of tender above rails ..	8 "

CARRIAGES AND WAGGONS.

Maximum wheel base for curves of 2000 feet radius	18 feet
Ditto ditto, 1500 feet radius ..	15 "
Ditto ditto, 1000 " ..	12 "
Inclination of cone of tires	$\frac{1}{20}$
Maximum breadth of tire	6 inches
Minimum ditto	5 "
Minimum thickness of tire over rail ..	$\frac{3}{4}$ inch
Minimum play for flanges	$\frac{3}{8}$ "
Maximum ditto	1 "
Clear width between wheels	4 ft. $5\frac{1}{2}$ in.
Maximum projection of flange below surface of rail	$1\frac{1}{4}$ inch
Minimum diameter of wheels	3 feet
Minimum diameter of axle at nave with $3\frac{3}{4}$ tons load per axle	4 inches
Ditto ditto, 5 tons load	$4\frac{1}{2}$ "
Ditto ditto, $6\frac{1}{2}$ tons load	5 "
Minimum diameter of axle journal with $3\frac{3}{4}$ tons load	$2\frac{5}{8}$ "
Ditto ditto, 5 tons load	3 "
Ditto ditto, $6\frac{1}{2}$ tons load	$3\frac{1}{4}$ "
Length of axle, centre to centre of journal	6 ft. $5\frac{1}{2}$ in.
Maximum length of journal	8 inches
Minimum ditto	5 "
Maximum thickness of steel spring plates	$\frac{1}{2}$ inch
Length of carriage springs	5 feet

Length of waggon springs	3 ft. 6 in.
Maximum deflection of springs under load	4 inches
Minimum ditto ditto	2 ”
Minimum ht. of break block above rail	5 ”
Height of centre of buffers above rails	3 ft. 5 in.
Distance of centre of buffers apart ..	5 ft. 9 in.
Distance of side chains apart	3 ft. 6 in.
Minimum diameter of buffers	14 inches
Minimum rounded projection	1 inch
Maximum breadth of carriage	8 ft. 7 in.
Ditto of waggons	7 feet
Maximum height of carriages and waggons	12 ft. 4 in.

French Railways.

(Perdonnet et Polonceau.)

Gauge	4 ft. $8\frac{1}{2}$ in.
Distance of rails apart, centre to centre	4 ft. $10\frac{3}{4}$in.
Distance between up and down line ..	5.11 to 6.6
Distance from rails to edge of ditch, in good ground in cutting	3 ft. 3 in.
Width of ordinary ditch at top	24 inches
Ditto ditto, at bottom	8 ”
Depth	36 ”
Width of parapet of bridges	26 feet
Height of keystone of bridges above rails	17 ”
Height of horizontal beams above rails	14 ”
Adhesion of wheels—	
In summer	$\frac{1}{4}$th of weight
In winter foggy weather ..	$\frac{1}{10}$th ”
Average	$\frac{1}{6}$th ”
Traction of trains per ton—	
Goods trains	8·82 lbs.
Passenger ”	17·0 ”
Express ”	22 ”

Technical Report of German Railway Union.

PERMANENT WAY AND BRIDGES.

Nicking lower flange of steel rails generally condemned.

Angled fish plates or check plates substituted for nicking.

Number of tons required for wear of one millimètre in steel rails:—On level lines with easy curves, 10 to 20 million tons; on gradients of 1 in 120, easy curves and moderate breaking, 6 to 7 millions; on gradients of 1 in 60 to 1 in 100, curves of 1600 feet, 4 millions; on gradients of 1 in 40 to 1 in 100, curves of 636 feet, 1 to 2 millions.

Old steel rails may be rolled over again for light tram rails.

Steel rails should not be of lighter section than iron; heads might be deeper, because they will last until fairly worn down.

Average diameter of rail height, 4·95 inches; depth of head, 1·25; breadth of foot, 4·15; width of web, ·55; angle for fish-bed, 16° to 19°.

Maximum length of rails from 24 to 30 feet.

Chloride of zinc most largely employed for impregnating sleepers, creosote next; use of sulphate of copper declining.

Cost of chloride of zinc is from $\frac{1}{2}$ to $\frac{1}{3}$ of the cost of creosoting.

Clean, hard slag ballast is the best for sleepers. Sleepers should be covered with clean ballast. Air-drying of sleepers before laying is desirable. Timber is more durable if felled in winter. Drying before pickling is desirable in the case of creosote, but not with chloride of zinc.

Hard wood sleepers should be bored for spikes, but not soft wood.

Check nuts, spring washers, and other methods for preventing fish bolts from working loose are not satisfactory.

Longitudinal iron sleepers, "Hilf" system, much used; Hartwick is a failure; Battig's system and Vauthaurin's longitudinal satisfactory; joint of sleepers and rails should be together. Cross ties, 2 per length of rail on straight and 4 on curves. Cross sleepers, Vauthaurin's system, most used. Gibs and cotters abandoned for clips and hook bolts.

Formation may be reduced to 10 feet for single lines and 22 for double lines by use of longitudinal iron sleepers.

Use of small plates between foot of rail and the sleepers

REPORT OF GERMAN RAILWAY UNION—*continued.*

with two holes on each side of the rail is the best to preserve gauge.

Suspended joint preferred to insistent joint.

Oil paint preferred to other coatings for bridges. New ironwork should be cleaned before painting by plunging first into acid and then into lime and water.

Expansion gear on bridges does not seem to be absolutely necessary.

Expansion gear was taken from a bridge 280 feet span without any evil result.

There is difficulty in obtaining steel of proper character for bridges, but steel bridges erected have been satisfactory.

Coned bolts are recommended to replace long rivets of more than 1 inch diameter.

Movable bridges should be so covered with distant signals, that releasing the gear to open them should automatically show danger signals.

WORKS AT STATIONS.

The distance between rail and guard at switches or crossings should be $1\frac{3}{4}$ inch on straight and $1\frac{5}{8}$ on curves extending for about 3 feet opposite the point of the crossing, then increased to $2\frac{1}{2}$ in the length of another 3 feet, and then curved off.

There is no advantage in giving a cant of 1 in 20 to rails and switches.

No general arrangement is adopted for ensuring position of switches.

Facing points should be locked on the switch tongue.

Steel crossings are considered superior to iron.

It is objectionable to allow wheels to run on their flanges through crossings.

Straight or curved switches are used in about the same proportions.

Iron switches are generally preferred to steel.

Facing points on a double line of railway are objectionable.

Fish-bolt fastening at head of switch is used about equally with pivot.

It is preferable on single lines to pass over facing points on straight rather than curve.

Fast trains running through should be kept on the straight line.

Report of German Railway Union—*continued.*

LOCOMOTIVES.

Six-coupled engines are chiefly used on long gradients above 1 in 40 and 4-coupled on short gradients.

Ratio of working cost does not differ much in 6 and 8 coupled engines, for ratio of tractive power.

Higher pressure than 150 lbs. is undesirable.

Majority of railways approve of connecting springs by lever, but advantages not marked.

Sliding axles recommended on 8-coupled engines of long wheel base and on shunting engines.

Two-wheel bogies, "Bissel" and "Nowotny" systems, considered preferable to 4-wheeled bogies.

Bogies considered to give greater speed on straight and greater safety on curves. "Nowotny" system preferred to "Bissel."

Mean value of experiments gives resistance ·0039 to ·0044 of the load (8·74 to 9·85 lbs. per ton).

Steel boilers are not generally recommended.

Pressure test of little value except as to tightness.

Steam dome is necessary where gradients are severe and variable.

Gussets generally preferred for staying front of fire-box.

General opinion that molecular changes do not take place in boilers.

No satisfactory plan for obviating grooving and pitting.

Steel tubes not recommended.

Water treated with lime and caustic soda in closed tanks prevents scale. Hot jets for washing out suggested.

Stay bolts generally preferred to crown bars for fire-boxes.

Steel and iron fire-boxes not approved.

Average radius for corners of fire-box about $7\frac{1}{2}$ inches.

Cast-iron fire-bars present no advantage; wrought-iron best for coke.

Steel preferred for axles and tires.

Use of phosphor bronze for bearings doubtful.

Lubricants for flanges going round curves advisable; either grease, petroleum, or water.

In large cylinders it is advantageous to pass the piston rod through the end of the cylinder cover.

Bessemer mild steel suitable for connecting and coupling rods, cranks, &c.

REPORT OF GERMAN RAILWAY UNION—*continued.*

Cotton packing filled with talc gives excellent results for stuffing boxes.

Injectors which do not suck preferred.

No smoke-consuming apparatus successful.

Archimedean screw sanding apparatus preferred.

Jet of water or steam not satisfactory for sanding.

Le Chatelier's break satisfactory.

CARRIAGES AND WAGGONS.

The "Mansel" ring used with good results for fastening tires.

Cracks in journal detected by cleaning carefully and then striking the end of the axle heavily with a hammer, when the oil lodged in the crack will start to the surface.

Fracture of axles not due to the use of breaks.

Wrought-iron spoke or disc wheels generally preferred.

Mild cast steel considered the best material for tires.

In continuous breaks the "Heberlein" are violent and irregular and subject to frequent breakages; "Westinghouse," "Steel," or "Smith's vacuum" satisfactory; "Achard" costly and troublesome.

For break blocks, wood wears too rapidly and causes wheels to skid; wrought iron wears the tires too rapidly; cast iron beneficial for tires, but wears quickly; ordinary steel causes heating; cast steel has some advantages and is cheaper in the end.

Advantages of 6-wheeled over 4-wheeled carriages doubtful.

Storied carriages used with success for special and local service.

Elastic packings between body and under-frame advantageous in diminishing noise.

For warming carriages, heating by steam is cheap and safe, but often fails in connections. Stoves and hot air cause risk of fire; hot-water tins are imperfect and costly, but safe.

For lighting carriages, stearine candles cheapest, colza oil next; gas dearer than oil in proportion of 11 to 8; gas is clean and gives the best light.

Arrangements for feeding and watering cattle *en route* not successful; preferable to have feeding stations provided at intervals.

REPORT OF GERMAN RAILWAY UNION—*continued.*

Materials for construction of waggons:—Open waggons entirely of iron, or iron with timber floors; covered waggons, the body of timber, the under-frames of iron.

Ordinary oil paint preferred for waggons.

WORKSHOPS.

Series of narrow roofs side by side of ridge or saw type preferred, with slate, tile, or galvanized iron.

For flooring, wood preferred. For repairing sheds and machine shops, flooring of blocks made from old sleepers; clay floors objectionable on account of dust.

Lighting of shops by electricity experimental, but not expected to supersede gas.

For heating tires reverberating furnaces preferred; ring-shaped furnaces successful.

Timber for waggons should be seasoned for several years. Some desiccate and impregnate with chloride of zinc.

SERVICE OF WAY.

For watching permanent way, women are successfully employed, but for signalling they should only assist.

Turn-tables and traversers not well adapted for marshalling whole trains.

For preventing vehicles breaking loose at stations, putting down breaks and coupling vehicles together is recommended.

SERVICE OF TRAINS.

Speed—36 miles per hour when there are no sharp curves and no *great* number of points to pass through; this holds good with facing points properly locked with signals.

For measuring power and speed of trains, no instruments are completely successful.

In checking speed on important sections, electrical contact instruments, for measuring the time between fixed points, answer.

For increasing adhesion in frost or fog, sanding the rails from sand-boxes on the engine is preferred.

REPORT OF GERMAN RAILWAY UNION—*continued.*

For ascending steep gradients, an auxiliary engine should be placed behind the train.

A tire is considered unsafe as soon as the rounded part of the flange is worn away.

Examination in colour blindness is necessary for railway servants whose duty it is to watch coloured signals. Communication between passenger and guard is not successful.

Sleeping carriages with one tier are preferred by passengers to those with two tiers.

SIGNALS.

Telegraph wires through tunnels should be well insulated, and protected with casing.

For block system, "Siemens'" is preferred; the Morse system with independent optical signals also recommended.

Distant signal wires to be compensated.

In distant signals actuated by electricity, the induced current is preferred to a constant current.

Signals are unnecessary on sidings, but should be retained on the main line.

Signals recognized by form are better than those shown by colour.

INCREASE TO GAUGE ON SHARP CURVES.

R = Radius of curve in feet.
x = Increase to be given to gauge if in eighths of an inch.
y = " " " if in inches.
z = " " " in terms of radius R.

$$x = \frac{4500}{R}. \qquad y = \frac{562 \cdot 5}{R}. \qquad z = \frac{46 \cdot 875}{R}.$$

The increase is in no case to exceed $\frac{7}{8}$ inch.

No increase is to be made on curves the radius of which exceeds 1600 feet.

Notes on Permanent Way.

(Von Weber and others.)

RAILS.

The breaking weight, as well as the lateral resistance, is greater in flange-rails than in double-headed rails of equal proportion. Too great rigidity of rails entails increased wear on the rails and rolling stock. The radius of the top table is generally too sharp, and should be increased to 24 inches.* The radius of the shoulder of the top table should be about ·55 inch.

The angle of the fish-planes with the horizontal plane, when the rail is upright, should be about 30°.

The web for rails from 60 to 75 lbs. per yard need not be more than $\frac{1}{2}$ to $\frac{3}{8}$ inch. The resistance to lateral displacement is increased by the friction between the rails and the wheels.

Rails which do not break joint have only 70 per cent. of the lateral strength of those which break joint.

BALLAST.

The character of the ballast has no important effect on the lateral resistance of the permanent way.

Filling ballast at the end of the sleepers does not practically increase the lateral resistance.

Short piles driven at the end of the sleepers do not increase to any appreciable extent the power of resistance to lateral force.

* Mr. Conybeare recommends a radius of 40 inches.

NOTES ON PERMANENT WAY—*continued.*

The force required to produce lateral displacement is directly proportional to the weight by which sleepers are pressed on the ballast.

If the ballast be not filled in at the ends of the sleepers, the elasticity of the rail will bring back sleepers to their original position, even after considerable displacement.

SPIKES.

Spikes driven for the first time have a greater holding power than those which have been driven and drawn several times.

Bellied spikes have only from ·7 to ·9 the adhesion of straight spikes of the same weight.

No advantage is gained by jagging or twisting spikes.

The points of spikes should be "chisel" form, so as to displace the grain of the timber endways.

The best proportion for the point of a spike is length = twice its breadth.

Straight spikes are preferable to those of taper form.

SLEEPERS.

Too long a bearing of the rail on the sleepers causes the sleepers to rock.

Distance of joint sleepers apart should be ·6 of the distance apart of the intermediate sleepers.

Sound sleepers of fir are compressed ·04 inch by a pressure of 80 or 100 lbs. per square inch, or by 60 lbs. after the sleeper has been subject to compression for some time.

NOTES ON PERMANENT WAY—*continued.*

The action of the train increases the compressibility of the timber.

The cellular tissue of soft sleepers is gradually destroyed by too great pressure.

Distribution of weight should be effected by increasing the bearing surface of plates and shoes, rather than by adopting a more rigid rail which destroys elasticity, or by increasing the number of sleepers which does not attain the desired end.

Soft sleepers allow of canting under lateral pressure from compression of the timber.

The sinking of *well-bedded* sleepers into the ground is insignificant.

It is estimated that the relative value of fir to oak is as 1 to $1\frac{3}{4}$.

The coefficient to resist the drawing of spikes is 300 lbs. per square inch of the surface of the spike in fir, and 600 lbs. in oak if lateral pressure is not used at the same time; if lateral pressure is also used, the coefficient is reduced to 160 in fir and 270 in oak.

Intermediate sleepers in fir should have two spikes on the outside of the rail, or a small plate to connect the inside with the outside spikes.

Joint sleepers or sleepers on sharp curves should have shoes or bed-plates.

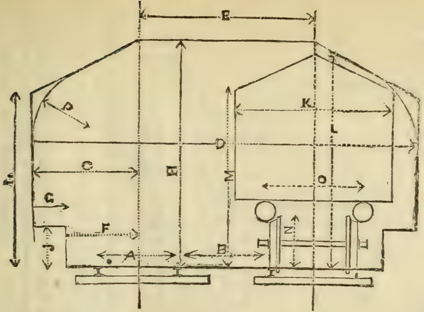
Holes for spikes should be bored quite through the sleepers.

The best size for holes is half the diameter of the spikes.

Bed-plates increase the resistance to lateral pressure by 60 to 100 per cent.

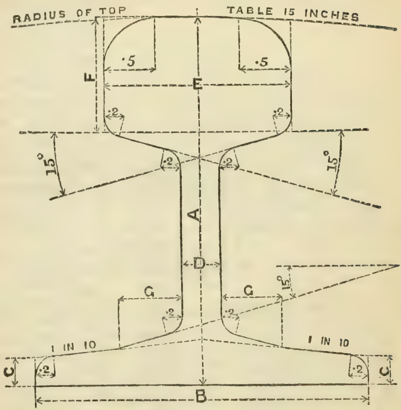
The enlargement of the gauge to an extent of $\frac{1}{4}$ or $\frac{3}{8}$ inch is not beyond the limits of elasticity, and does not impair the tenacity of the spikes.

Gauge of Railways.



Gauge.	A.	B.	C.	D.	E.	F.	G.	H.	I.	J.	K.	L.	M.	N.	O.	P.
Broad	7 0¾	6 0	7 0	27 5	13 5	5 7¼	1 4¾	16 0	14 0	2 9	11 6	15 0	10 6	3 1	5 10	6 0
Narrow ..	4 8½	6 0	6 7	24 3¾	11 1¾	4 7	2 0	14 6	11 0	2 0	8 4	13 6	11 7	3 4	5 8	2 0
Irish	5 3	6 0	8 2	28 0	11 8	—	—	14 6	10 6	—	—	—	—	—	—	8 0
Indian.. ..	5 6	6 0	6 11½	25 10	11 11	5 2½	1 9	14 6	11 6	3 0	10 6	13 6	11 6	3 6	6 5	3 0
Prussian ..	4 8½	6 2¼	6 7	24 6	11 4	5 5	1 2	15 9	15 9	2 6	8 7	13 6	12 0	3 5	5 9	6 7
Metre Indian	3 3⅜	8 6⅝	6 6	24 10	11 10	4 5	2 1	11 10	9 10	2 0	8 4	11 0	10 2	1 10	—	3 3

Standard for Steel Rails.



The dimensions, &c., marked on the diagram are common to all sections.

The dimensions that vary with each section are given in the following table:—

Dimensions in Inches and Decimals of an Inch.

	Mark	Weight of Rail. Lbs. per yard.									
		30	35	40	45	50	55	60	65	70	75
Height of rail ..	A	3·0	3·25	3·5	3·75	4·0	4·25	4·5	4·75	5·0	5·25
Width of flange ..	B	2·80	3·0	3·20	3·40	3·60	3·80	4·0	4·20	4·40	4·60
Thickness of flange	C	·24	·25	·26	·27	·28	·29	·30	·31	·32	·33
,, web..	D	·34	·35	·36	·37	·38	·39	·40	·41	·42	·43
Width of head ..	E	1·60	1·70	1·80	1·90	2·00	2·10	2·20	2·30	2·40	2·50
Depth of ditto ..	F	·85	·97	·99	1·15	1·22	1·27	1·30	1·34	1·36	1·36
Width of fish-bed	G	·50	·55	·60	·65	·70	·75	·80	·85	·90	·95

Rules for the Weight of Rails.

W = Weight of rail in lbs. per yard.
L = Greatest load on one driving wheel in tons.
$W = L \times 12$.

Sectional area of rail in inches × 10 for iron or 10·4 for steel = weight of rail in lbs. per yard. Weight of rail in lbs. per yard × 1·571 = weight of rails for a mile of single line of railway, in tons.

Memoranda on Rails, &c.

Depth of rails, from 4½ to 5 inches for first-class railway.
Thickness of middle web, ⅝ inch.
Width of top table, 2½ inches.
Radius of ditto, 12 to 40 inches.
Width of flange (if a flanged rail), 4¾ inches.
Thickness of ditto .. .. ½ inch.
Weight of fish plates, about 20 lbs. per pair.
100 fish bolts weigh about 1 cwt.
Cast-iron intermediate chairs, each 21½ lbs.
Ditto joint „ 39 „

Fifteen larch sleepers creosoted, 9 feet 6 inches long, 5 × 10 inches at the small end, weigh 1 ton.

Permanent Way, Indian State Railways, 5 ft. 6 in. Gauge, Steel Flange Rails, 62 lbs. per yard.

	Weight, lbs.		Quantity required for 1 mile Single Line.						
			Allowance for waste per cent.	Actual requirements for Rails of lengths.			Rails in assorted lengths.		
				30 ft.	27 ft.	24 ft.	No.	Tons.	Total tons.
30 ft. rails	each	620	—	352	—	—	300	83·02	96·96
27 „	„	558	—	—	391·11	—	40	9·07	
24 „	„	496	—	—	—	440	22	4·87	
Fish plates	pair	18	5	352	391	440	380	3·05	13·75
Fish bolts	each	·875	5	1408	1564	1760	1520	·60	
Spikes	„	·7	10	7744	7822	7920	8600	2·70	
Bearing plates	„	4·483	5	3520	3520	3520	3700	7·40	
Sleepers*	„	125·75	5	1760	1760	1760	1850	104	104
							Total ..	..	214·71

* Creosoted, 10 ft. × 10 in. × 5 in.

PERMANENT WAY, INDIAN STATE RAILWAYS, Mètre Gauge.
STEEL FLANCH RAILS, 41½ lbs. per yard.

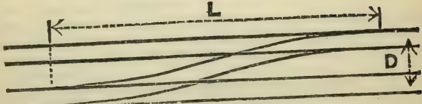
	Weight, lbs.		Allowance for waste per cent.	Quantity required for 1 mile Single Line.					
				Actual requirements for Rails of lengths.			Rails in assorted lengths.		
				24 ft.	21 ft.	18 ft.	No.	Tons.	Total tons.
24 ft. rails	each	327·11	—	443·88	—	—	388	56·66	64·49
21 „	„	288·75	—	—	502·86	—	44	5·67	
18 „	„	250·25	—	—	—	580·22	22	2·46	
Fish plates	pair	9·18	5	444	503	580	475	1·94	7·72
Fish bolts	each	·85	5	1776	2012	2321	1900	·72	
Spikes ..	„	·53	10	8878	9054	9283	11000	2·60	
Bearing plates	„	1·31	5	3995	4023	4061	4200	2·46	
Sleepers	„	59	5	1998	2012	2031	2100	55·31	55·31
						Total			127·82

POINTS AND CROSSINGS.

Ordinary Crossing, Narrow Gauge.

Length from point to crossing	= 75 feet
Total length from point to point ..	= 165 „
Radius	= 600 „
Angle of crossing	= 1 in 10
Length of switches..	= 12 to 15 feet
Throw of ditto, at point	= 4 inches
Clearance of ditto, „	= 3½ „
Length of guard rail	= 8 feet
Clearance of ditto	= 1½ inch

RAILWAY SIDINGS, &c.

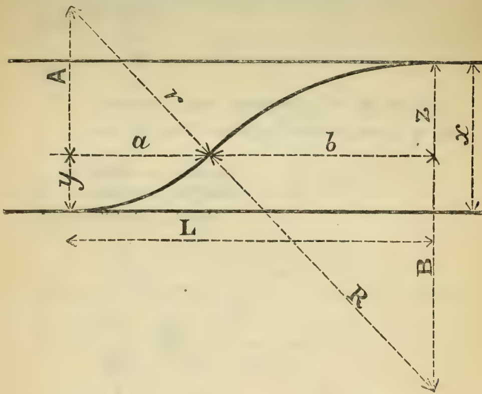


R = Radius of curves.
L = Length over points.
D = Distance between centres of lines of siding.

$$L = 2\sqrt{D.R - (\tfrac{1}{2}D)^2}.$$

Points and Crossings.

TURN-OUTS OF UNEQUAL RADII.



R and r = Radii of the curves respectively
x = distance apart of the tracks.
L = Length of turn-out.

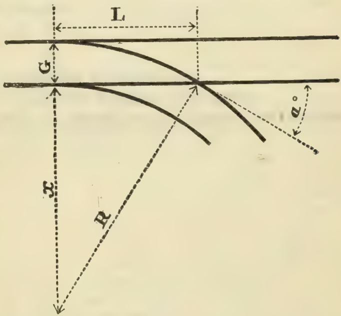
$$y = \frac{r\,x}{R + r}.$$

$$z = x - y.$$

$A = r - y$; $a = \sqrt{y\,(r + A)}$.
$B = R - z$; $b = \sqrt{z\,(R + B)}$.
$L = a + b$.

Points and Crossings.

CURVE RUNNING FROM STRAIGHT LINE.



R = Radius of curve.
G = Gauge of railway.
a° = Angle of crossing.
$x = \text{R} - \text{G}$.
L = Length from tangent point of curve to the centre of the crossing $= \sqrt{(\text{R} + x)\,\text{G}}$.

$$\text{Sin. } a^\circ = \frac{\text{L}}{\text{R}}.$$

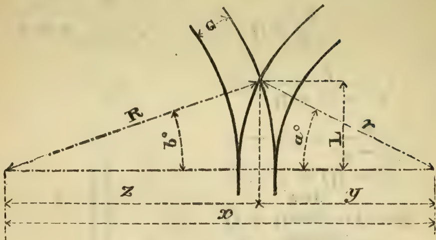
$$\text{R} = \frac{\text{G}}{\text{Versin. } a^\circ}.$$

Lead of crossing = cotan. a°.

In flat curves the width required for the clearance of the flange of the wheel, and for the width of the rail at the heel of the switch, render it necessary to make some allowance in the theoretical length L.

POINTS AND CROSSINGS.

CURVE RUNNING FROM REVERSE CURVE.



R and r = Radii of the two curves respectively.

G = Gauge of the railway.

L = Length from tangent point of curve to the centre of the crossing.

$$x = (R + r) - G.$$

$$z - y = \frac{R^2 - r^2}{x} = 0 \text{ if } R = r.$$

$$y = \frac{x - (z - y)}{2} = \frac{x}{2} \text{ if } R = r.$$

$$z = x - y \qquad = y \text{ if } R = r.$$

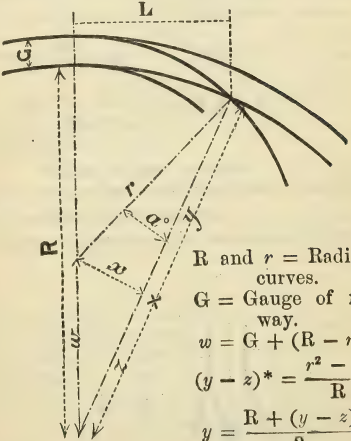
$$L = \sqrt{r^2 - y^2} = \sqrt{R^2 - z^2}.$$

$$\text{Sin. } a^\circ = \frac{L}{r}; \qquad \text{Sin. } b^\circ = \frac{L}{R}.$$

Angle of crossing $= a^\circ + b^\circ$.

POINTS AND CROSSINGS.

CURVE RUNNING FROM INSIDE OF CURVE.



R and r = Radii of curves.

G = Gauge of railway.

$$w = G + (R - r).$$

$$(y - z)^* = \frac{r^2 - w^2}{R}.$$

$$y = \frac{R + (y - z)}{2}.$$

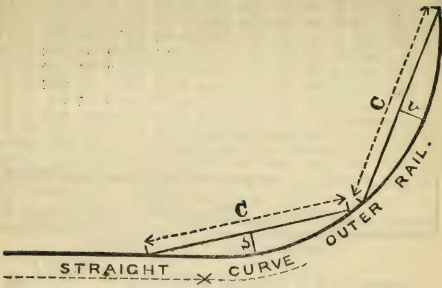
$$x = \sqrt{r^2 - y^2}. \qquad L = \frac{R\,x}{w}.$$

Sin. $a^\circ = \frac{x}{r}$; a° = Angle of crossing.

* If w be greater than r, then

$$(z - y) = \frac{w^2 - r^2}{R}; \quad z = \frac{R + (z-y)}{2}; \quad y = R - z.$$

Practical Rule for Determining the Elevation of the Outer Rail for any Radius or for any Combination of Curve with Straight. (J. Price, 'Min. Inst. Civ. Eng.,' vol. xxxii.)



V = Maximum velocity of trains in feet per second.

G = Gauge of the railway in feet.

C = The length in feet of a chord whose versed sine V will equal the required elevation.

$$C = \tfrac{1}{2} V \sqrt{G}.$$

For 40 miles per hour the length of C = 68·7 feet for 5′ 6″ gauge, or = 63·6 feet for 4′ 8½″ gauge = approximately a Gunter's chain of 66 feet.

Make a chord = C and stretch it on the inner side of the rails: the distance of the rails from it at its middle will equal the proper elevation, no matter what the radius may be.

Elevation of Outer Rail on Curves.

Let D = Diameter of carriage wheels in feet.

W = Width of gauge in feet.

P = Lateral play between flange and rail in ft.

$\frac{1}{N}$ = Ratio of inclination of tire.

V = Velocity in miles per hour.

R = Radius of curve in feet.

E = Elevation of outer rail in *inches*.

$$E = \frac{[\cdot 782\ V^2\ (N\ D\ W)] - 4\ P\ R}{N\ D\ R}.$$

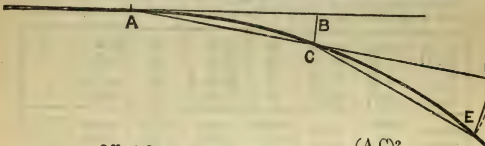
ANOTHER RULE.

$$W\frac{V^2}{1\cdot 25\ R} = \text{Elevation of outer rail in } inches.$$

Speed Table for Trains.

Speed per hour.	Time of performing ¼ mi.	½ mi.	1 mile.	Speed per hour.	Time of performing ¼ mi.	½ mi.	1 mi.	Speed per hour.	Time of performing ¼ mi.	½ mi.	1 mi.
miles	m. s.	m. s.	m. s.	miles	m. s.	m. s.	m. s.	miles	m. s.	m. s.	m. s.
5	3 0	6 0	12 0	24	0 37	1 15	2 30	43	0 20	0 41	1 23
6	2 30	5 0	10 0	25	0 36	1 12	2 24	44	0 20	0 40	1 21
7	2 8	4 17	8 34	26	0 34	1 9	2 18	45	0 20	0 40	1 20
8	1 52	3 45	7 30	27	0 33	1 6	2 13	46	0 19	0 39	1 18
9	1 40	3 20	6 40	28	0 32	1 4	2 8	47	0 19	0 38	1 16
10	1 30	3 0	6 0	29	0 31	1 2	2 4	48	0 18	0 37	1 15
11	1 21	2 43	5 27	30	0 30	1 0	2 0	49	0 18	0 36	1 13
12	1 15	2 30	5 0	31	0 29	0 58	1 56	50	0 18	0 36	1 12
13	1 9	2 18	4 37	32	0 28	0 56	1 52	51	0 17	0 35	1 10
14	1 4	2 8	4 17	33	0 27	0 54	1 49	52	0 17	0 34	1 9
15	1 0	2 0	4 0	34	0 26	0 53	1 46	53	0 17	0 34	1 7
16	0 56	1 52	3 45	35	0 25	0 51	1 43	54	0 16	0 33	1 6
17	0 53	1 46	3 31	36	0 25	0 50	1 40	55	0 16	0 32	1 5
18	0 50	1 40	3 20	37	0 24	0 48	1 37	56	0 16	0 32	1 4
19	0 47	1 34	3 9	38	0 23	0 47	1 34	57	0 15	0 31	1 3
20	0 45	1 30	3 0	39	0 23	0 46	1 32	58	0 15	0 31	1 2
21	0 42	1 25	2 51	40	0 22	0 45	1 30	59	0 15	0 30	1 1
22	0 40	1 21	2 43	41	0 21	0 43	1 27	60	0 15	0 30	1 0
23	0 39	1 18	2 36	42	0 21	0 42	1 25				

Ranging Curves by Offsets, in Equal Chords.

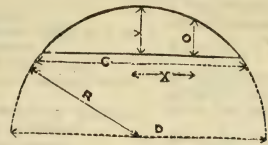


Offset from tangent B C $= \dfrac{(A\,C)^2}{2 \text{ radius}}$

Offset from chord produced D E $= \dfrac{(C\,E)^2}{\text{radius}}$

A B = A C, and C D = C E.

Rules for the Versed Sines and Ordinates of Curves.



Versed sine $V = R - \sqrt{R^2 - (\frac{1}{2}C)^2}$

Diameter of circle $D = \dfrac{(\frac{1}{2}C)^2}{V} + V$

Length of ordinate $O = \sqrt{R^2 - X^2} - (R - V)$

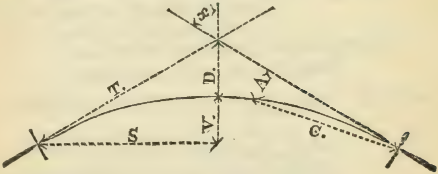
Bending Rails for Curves.

Approximate Rule for Bending Rails.

L = Length of rails in feet.
R = Radius of curve in feet.
V = Versed sine of rail when bent.

V in feet $= \dfrac{0 \cdot 13\,L^2}{R}$. V in inches $= \dfrac{1 \cdot 56\,L^2}{R}$.

FORMULÆ FOR SETTING OUT RAILWAY CURVES.



R=Radius of curve.	$R=\dfrac{1719\,C}{A}$.
T=Length of tangent.	R=T (tan. x).
x=Half angle of intersection.	T=R (cotang. x).
D=Distance of centre of curve from intersection.	D=R (cosecant $x-1$).
C=Any chord.	$A=\dfrac{1719\,C}{R}$.
A=Tangential angle of C in minutes.	S=R (cosine x).
	V=R (coversine x).

Number of chords in the curve $=\dfrac{5400-x}{A}$.

Length of the curve $= \cdot 000582\,R\,(5400 - x)$.

Note.—x and A in the two preceding formulæ must be expressed in minutes.

TABLE OF TANGENTIAL ANGLES FOR 1 CHAIN CHORDS.

Rad. of Curve Chains.	Tangl. Angle.	Rad. of Curve Chains.	Tangl. Angle.	Rad. of Curve Chains.	Tangl. Angle.	Rad. of Curve.	Tangl. Angle.
5	5° 43·8	15	1° 54·6	40	42′·97	1 mile	21′·48
8	3 34·87	20	1 25·95	45	38 ·2	1¼ "	17 ·19
9	3 11·	25	1 8·76	50	34 ·38	1½ "	14 ·33
10	2 51·9	30	57·3	60	28 ·65	1¾ "	12 ·28
12	2 23·25	35	49·11	70	24 ·55	2 miles	10 ·74

Note.—The angle for 2 chain chords is double the angle for 1 chain chords. The angle for ½ chain chords is ½ the angle for 1 chain chords.

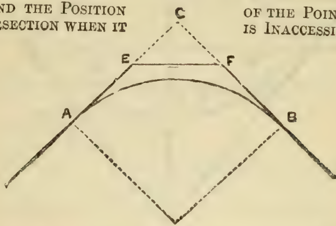
Curves of less than 20 chains radius should be set out in ½ chain chords. Curves of more than 1 mile radius may be set out in 2 chain chords.

The angles in the above Table are in degrees, minutes, and decimals of minutes.

TABLE OF TANGENTIAL ANGLES FOR CHORDS OF 1 FOOT AND 100 FEET. (Hurst.)

Radius of Curve.	Angle of Deflection. Chord 1 foot.	Angle of Deflection. Chord 100 feet.		Radius of Curve.	Angle of Deflection. Chord 1 foot.	Angle of Deflection. Chord 100 feet.		Radius of Curve.	Angle of Deflection. Chord 1 foot.	Angle of Deflection. Chord 100 feet.	
feet.	min.	d.	m.	feet.	min.	d.	m.	miles.	min.	d.	m.
500	3·438	5	43·77	3000	0·573	0	57·30	1/8	2·604	4	20·44
600	2·865	4	46·48	3500	0·491	0	49·11	1/4	1·302	2	10·22
700	2·456	4	5·55	4000	0·430	0	42·97	1/2	0·651	1	5·11
800	2·149	3	34·86	4500	0·381	0	38·20	3/4	0·434	0	43·41
900	1·910	3	10·99	5000	0·344	0	34·38	1	0·326	0	32·55
1000	1·719	2	51·89	5500	0·313	0	31·25	1¼	0·260	0	26·04
1100	1·563	2	36·26	6000	0·286	0	28·65	1½	0·217	0	21·70
1200	1·432	2	23·24	7000	0·246	0	24·56	1¾	0·187	0	18·70
1500	1·146	1	54·59	8000	0·215	0	21·49	2	0·163	0	16·28
2000	0·859	1	25·94	9000	0·191	0	19·1	2½	0·130	0	13·02
2500	0·688	1	8·76	10000	0·172	0	17·19	3	0·109	0	10·85

TO FIND THE POSITION OF THE POINT OF INTERSECTION WHEN IT IS INACCESSIBLE.



When C is inaccessible, run any line E F, then

$\angle CEF = 180° - \angle AEF$

also $\angle CFE = 180° - \angle BFE$ therefore

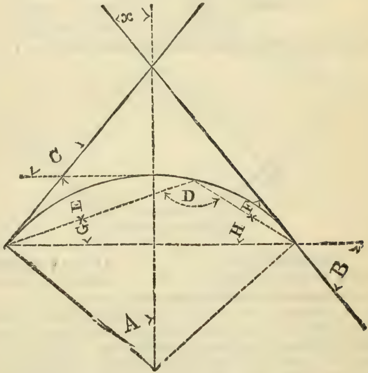
$\angle ACB = 180° - (\angle CEF + \angle CFE)$

and side $EC = \dfrac{EF \times \sin. \angle CFE}{\sin. \angle ACB}$

$$FC = \frac{EF \times \sin. \angle CEF}{\sin. \angle ACB}.$$

Railway Curves.

RELATIVE VALUE OF USEFUL ANGLES TO ANGLE OF INTERSECTION.



Let x = Half the angle of intersection,

then $A = 90° - x$	$D = 90° + x$
$B = 90° - x$	$E + F = 90° - x$
$C = 90° + x$	$G + H = 90° - x$

Setting out with Two Theodolites

If any two lines be set out from the starting points of the curve having the sum of their tangential angles $(E + F) = 90° - x$; the intersection of these two lines will be a point in the curve.

By a series of such points the whole curve may be set out if the country be sufficiently open to allow of it.

Resistance of Trains.

W = Weight of vehicle without wheels and axles.
w = Weight of wheels and axles.
D = Diameter of wheels on tread.
d = Diameter of journal.
F = Coefficient of axle friction.
= say ·018 with oil, or ·035 with grease.
f = Coefficient of rolling friction.
= say ·001.
R = Resistance of vehicle.

$$R = f(W + w) + \left(W F \frac{d}{D}\right).$$

Resistance of Curves.

('Trans. Inst. Civ. Eng.,' vol. xxxi., Morrison.)

W = Weight of vehicle.
R = Radius of curve.
D = Distance of rails apart from tread to tread.
L = Length of rigid wheel base.
F = Coefficient of friction of wheels on rail.

$$\text{Resistance due to curve} = \frac{W F (D + L)}{2 R}.$$

The coefficient F will vary according to the weather from ·1 to ·27.

Resistance in Lbs. per Ton of Train due to Curves of different Radii, with different Wheel Bases.

Gauge, 4 feet $8\frac{1}{2}$ inches. Rails dry.

Length of Rigid Wheel Base.	Resistance per Ton due to Radius of Curve in feet.				
	600	1000	1500	2000	5000
feet.	lbs.	lbs.	lbs.	lbs.	lbs.
10	7·5	4·6	3·1	2·3	0·9
12	8·5	5·1	3·4	2·5	1·0
14	9·5	5·7	3·8	2·8	1·1
16	10·5	6·3	4·2	3·1	1·2

Metre (3 feet $3\frac{3}{8}$ inches) Gauge.

Resistance in Lbs. per Ton of Train due to Curves of different Radii, with different Lengths of Wheel Base. (Rails dry.)

Length of Rigid Wheel Base.	Resistance in Lbs. per Ton due to Curves whose Radius in Feet is					
	300	600	1000	1500	2000	5000
feet.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
6	9·4	4·7	2·8	1·8	1·4	·56
7	10·4	5·2	3·1	2·1	1·6	·62
8	11·4	5·7	3·4	2·3	1·7	·69
10	13·4	6·7	4·0	2·7	2·0	·81
12	15·4	7·7	4·6	3·1	2·3	·93

Tractive Power of Locomotives.

D = Diameter of cylinder in inches.
P = Mean pressure of steam in cylinders in lbs. per square inch.
L = Length of stroke in inches.
W = Diameter of driving wheel in inches.
T = Tractive force on rails in lbs.

$$T = \frac{D^2 P L}{W}.$$

Effective Pressure of Steam on Piston,

With Different Rates of Expansion.—Boiler pressure being assumed as 100 lbs. per square inch.

			Effective pressure.
Steam cut off at	$\frac{3}{4}$	of stroke	= 90
"	$\frac{2}{3}$	"	= 80
"	$\frac{1}{2}$	"	= 69
"	$\frac{1}{3}$	"	= 50
"	$\frac{1}{4}$	"	= 40

Rule to find the Load which an Engine will take on a given Incline.

G = Resistance due to gravity on the steepest gradient in lbs. per ton (see "Resistance of Trains").
R = Resistance due to assumed velocity of train in lbs. per ton.
T = Tractive power of engine in lbs. as found above.
W = Weight of engine and tender in tons.
L = Load the engine can take in tons, including the weight of the waggons, but not that of engine and tender.

$$L = \frac{T}{G + R} - W.$$

Resistance of Trains.

(Harding's Formula.)

T = Weight of train in tons.
V = Velocity in miles per hour.
A = Area of its frontage in square feet.
B = Its volume in cubic feet.
R = Resistance in lbs. on a level.

$$R = T\,(6 + \cdot33\,V) + 0025\,V^2\,A.$$
$$= T\,(6 + \cdot067\,V) + \cdot00002\,V^2\,B.$$

Experiment has shown that at lower speeds the formula gives too high results.

Table showing Results of Experiment compared with Formula.

Velocity, Miles per Hour.	Weight in Tons.	Resistance in Lbs.	
		By Formula.	By Experiment.
16	20½	13·2	8·5
19	40⅔	12·9	8·5
21	18	16·7	12·6
25	40¾	16·6	12·6
27	40¼	17·7	12·6
31	15½	25·4	23·4
32	14½	27·2	22·5
34	30½	23·1	25
34	18	27·2	23·4
35	21½	26·1	22·5
39	24	31·0	30
47	31¾	33·1	33·7
50	30	35·3	32·9
53	25	42·1	41·7
61	21½	54·8	52·6

Resistance of Trains.

Approximate Rule.*

V = Velocity of train, miles per hour.
R = Resistance, lbs. per ton of train.
$R = 6 + \cdot 009\, V^2$.

This is under the assumption that the weather is calm, the road level, straight, and properly maintained, and the rolling stock in good order.

Side winds press the flanges of the wheels against the rails and greatly increase the friction; wind, curves, or imperfections of the road will very largely increase the resistance, probably by 50 or 60 per cent.

V, miles per hour	10	15	20	25	30	35	40
R, lbs. per ton ..	6·9	8·0	9·6	11·6	14·1	17·0	20·4
V, miles per hour	45	50	55	60	65	70	75
R, lbs. per ton ..	24·1	28·5	33·2	38·4	44·0	50·1	56·6

Resistance Due to Gravity.

D = Declivity of gradient, feet per mile.
$\frac{1}{G}$ = Rate of gradient.
R = Resistance in lbs. per ton of train.

$R = 2240 \frac{1}{G}$. $D = 5280 \frac{1}{G}$.

Gradient, 1 in	20	25	30	35	40	45	50	55	60
D, feet per mile	264	211·2	176	150·9	132	117·3	105·6	96·0	88·0
R, lbs. per ton	112	89·6	74·7	64·0	56·0	49·8	44·8	40·7	37·3
Gradient, 1 in	70	80	100	120	150	200	300	400	500
D, feet per mile	75·4	66·0	52·8	44·0	35·2	26·4	17·6	13·2	10·6
R, lbs. per ton	32·0	28·0	22·4	18·7	14·9	11·2	7·5	5·6	4·5

* Modified, for oil lubrication; from D. K. Clark's formula $\frac{V^2}{171} + 8$ for lubrication by grease.

Adhesive Power of Locomotives.

Adhesion per ton of load on the driving wheels—

When the rails are very dry,	600 lbs.	per ton.
When the rails are very wet,	550	,,
In ordinary English weather,	450	,,
In misty weather if the rails are greasy	300	,,
In frosty or snowy weather,	200	,,

In coupled engines the adhesive force is due to the load on all wheels coupled to the driving wheels.

The adhesive power must exceed the tractive force of an engine on the rails, otherwise the wheels will slip. For loads on driving wheels, see below.

Distribution of Weight in Locomotives.

The average distribution of the weights of a six-wheeled locomotive on its wheels is—

Assuming the total weight of the engine in working order to be 1:

	Passenger Engines.	Goods Engines.
Load on leading wheels	32	·34
,, on driving wheels	·48	·36
,, trailing wheels	·20	·30
Total weight of engine	1·00	1·00

Passenger engines, 4 ft. $8\frac{1}{2}$ in. gauge, average	from 30 to 35	tons.
Goods engines	,, 35 to 40	,,
Mètre gauge	,, 18 to 20	,,

Tractive Force that may be developed in a Locomotive.

S = Square feet of heating surface.
V = Velocity in miles per hour.

$$T = \text{Tractive force in lbs.} = 374\,\frac{S}{V}.$$

Rope Inclines.

W = Weight of one train in tons (vehicles only).
w = Weight of the load (passengers or goods) in tons.
y = Weight of the cable in tons (see "Ropes").
r = Resistance on the level = say ·006 at slow speeds.
$\frac{1}{x}$ = Rate of inclination.
V = Velocity in miles per hour.
HP = Actual horse-power required, to which should be added 25 or 30 per cent. for contingencies, friction of rope, &c.

$$HP = 6\,V\left[\frac{W + w + y}{x} + r\,(W + w + 2\,y)\right] \text{ for single rope.}$$

$$HP = 6\,V\left[\frac{w + y}{x} + 2\,r\,(W + w + y)\right] \text{ for double rope}$$

("Tail end" system).

This formula is based on the assumption that the vehicles of the ascending train are balanced by those of the descending train.

$$HP = 6\,V\left[\frac{W + w + \frac{y}{2}}{x} + r\,(W + w + 4\,y)\right] \text{ for endless rope.}$$

San Paulo Railway Incline.

('Min. Inst. Civ. Eng.,' vol. xxx.)

Four lifts, the longest $1\frac{1}{3}$ mile long; gradient, 1 in 9·75; "Tail end" system. On the upper half of each lift, 3 rails are laid; but on the lower half, 2 rails forming a single line; half-way is a crossing siding, with 4 rails about 100 feet long in the clear, with self-acting switches at the lower end. The bank top of each lift is on a grade of 1 in 75, and 3 lines of rails 250 feet long are laid, the centre for down trains. Radii of curves 30 to 80 chains.

Ropes, steel wire (10 B.W.G.), 6 strand, 4 inches circumference, working load 4 to $4\frac{1}{2}$ tons; life of rope about 2 years.

Pulleys, wrought iron with cast core, 12 inches diameter, 5 to 7 yards apart on curves, 10 yards on straight.

Two engines, 26-inch cylinders, 5 feet stroke, 22 revolutions per minute, 30 lbs. boiler pressure.

Horizontal pulleys and winding drums 10 feet diameter.

Special breaks to clip the rails.

CONTINUOUS RAILWAY BREAKS.

W = Weight of train.
V = Velocity in feet per second.
D = Distance travelled before stopping.
R = Mean retarding force.
H = Height corresponding to velocity V.
F = Accumulated work.
g = Gravity, say 32·2.

$$R = F D; \; H = \frac{V^2}{2g}; \; F = \frac{W V^2}{2g}; = \cdot 0155 \, W V^2.$$

Trains about 200 tons.
Train resistance 9 lbs. per ton, or ·4 per cent. of gross weight.
Friction of engine and tender, not reckoning curves, winds, or gradients .. .. } ·62 " "
Retarding influences, average 7·62 " "
Distance of stopping at 30 miles per hour 470 feet.
" " 45 " " 1000 "
" " 60 " " 1870 "

	776 to 1100 feet with sand.
	814 " 1600 " without "
Foot-tons per second	1017 " 675 " with "
	964 " 491 " without "

Tender and break van's break 2·36 per cent.

COEFFICIENT OF FRICTION, CAST IRON ON STEEL.

Velocity, Miles per hour.	From commencement of Experiment.				
	0	5 Seconds.	10 Seconds.	15 Seconds.	20 Seconds.
2	·250	—	—	—	—
6·8	·242	—	—	—	—
13·6	·210	·193	—	—	—
17	·205	·157	—	·110	—
20·4	·182	·152	·133	·116	·099
27·3	·171	·130	·119	·081	·072
30·7	·163	·107	·099	—	—
34·1	·153	—	—	—	—
37·5	·152	·096	·083	·069	—
40·9	·144	·093	—	—	—
47·7	·132	·080	·070	—	—

By Galton's experiments with cast-iron blocks on steel tires, coefficient of friction varied from ·242 at 10 miles, to ·116 at 50 miles per hour.

BREAK EXPERIMENTS.

(Royal Commission Railway Accidents, 1877.)

A, Clarke and Webb; B, Smith's vacuum; C, Westinghouse air; D, Clarke's hydraulic; E, Barker's hydraulic; F, Fay's; G, Steel MacInnes; H, Westinghouse vacuum.

	A	B	C	D	E	F	G	H
Weight of engine empty .. tons	30·5	29·6	35·7	33·9	35·7	25·3	33·45	33
Do. tender, do. „	12·05	14·7	14·5	14·7	14·5	10·6	15·05	15·3
No. of carriages ..	13	13	13	13	13	13	13	13
No. of break vans..	2	2	2	2	2	2	2	2
Weight of train loaded .. tons	248	260	207	200	215	195	200	209
Friction of vehicles per cent. gross load	0·35	0·36	—	0·45	—	0·33	0·46	0·25
Friction of engines and tenders ..	0·575	0·785	—	—	—	—	—	—
Retarding force, all breaks in percentage of gross load with sand	7·79	7·47	10·61	—	7·64	7·60	7·33	5·88
Do. without sand ..	6·21	5·72	10·04	8·31	6·47	5·75	4·94	5·26
Tenders and break vans only	2·90	2·19	—	2·31	—	—	2·35	2·03
Distance of stop at 60 miles per hour, all breaks with sand .. .. feet	1540	1612	1128	—	1572	1580	1640	2044
Do. without sand „	1920	2100	1200	1448	1860	2088	2432	2284
Time required to put on break, secs.	—	4	1¼	—	5¼	—	—	7¾
Do. to take off „	—	—	3	—	8½	—	—	—

Time required to put on hand breaks = 3 seconds.

Approximately a good continuous break will stop a train in one-third the distance run when ordinary hand breaks are used. In none of the systems experimented upon could the stopping be applied too suddenly for safety. The break pressure should be taken off the moment before the train comes to rest, in order to avoid sudden shocks.

The difference in results is mainly owing to the rapidity with which the break can be put on.

Wood and cast iron do not appear to differ in skidding power.

Distance in yards at which trains should be capable of being brought to rest on the level $= 0\cdot11\ V^2$ when V = velocity in miles per hour.

V, Miles per hour.	30	35	40	45	50	55	60
Stop in yards ..	99	135	176	223	275	333	396

AXLES FOR RAILWAY CARRIAGES AND WAGGONS.

D = Diameter of journal in inches.
W = Weight on journal in tons.
L = Length of journal in inches.
S = Maximum stress allowed in tons per square inch on sectional area of journal.

$$D = 2\sqrt[3]{\frac{2\,W\,L}{3{\cdot}14\,S}}.$$

L = for carriages and waggons from $2\frac{1}{4}$ to $2\frac{3}{4}$ D.

DIMENSIONS OF AXLES OF CARRIAGES AND WAGGONS AND TENDERS.

Wheel load, tons	2	$2\frac{1}{2}$	3	$3\frac{1}{2}$	4	$4\frac{1}{2}$
Diameter of journal, inches	$2\frac{1}{2}$	$2\frac{7}{8}$	$3\frac{1}{4}$	$3\frac{1}{2}$	$3\frac{3}{4}$	4
Length, inches	$6\frac{1}{4}$	$7\frac{1}{4}$	8	9	10	10

Minimum diameter to which journals may be turned down

$$d = 0{\cdot}9\ \sqrt[3]{W\,L}.$$

Usual proportion of journal L × D per ton of load, from $8\frac{1}{2}$ to $9\frac{1}{2}$ square inches.

Distance which axles should run without repair, 18,000 miles. Axle tests 3 per 100.

VICKERS' TESTS FOR STEEL AXLES.

Straight axles should have an ultimate tensile strength of not more than 23 tons per square inch. This test can only be made by destroying the tested axles. Crank axles should also have a maximum tensile strength of 23 tons. The piece of steel cut out to shape the web is the best for testing. A piece cut off and unhammered should bear blows until it is bent completely double without showing any defect.

Tires of Wheels.

Thickness of tire on tread in inches = T.
Minimum thickness to which tire may be turned = t.

	4 ft. 8½ in. Gauge.			Mètre Gauge.		
	Engine.	Carriage.	Waggon.	Engine.	Carriage.	Waggon.
T, inches .. =	2·5	2·25	2·25	2	1·77	1·77
t, „ iron =	1	1	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{3}{4}$
t, „ steel =	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{2}$

After carriage tires have been turned to the minimum for carriages they may be used under goods waggons.

Mild steel tires should be guaranteed for 100,000 miles with a penalty for all above 20 per cent. that fail under 150,000 miles.

Vickers' Test for Steel Tires.

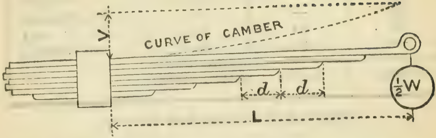
The tire placed vertically on a solid bearing should bear a series of blows from the fall of a tup weighing 1 ton; 1st fall, 5 feet; 2nd, 10 feet; 3rd, 15 feet, to be continued until partial or complete failure; the tire in its vertical position to yield $\frac{1}{6}$th of its diameter before breaking.

A piece of the tire thus tested ought to bear a tensile strength of 47 tons per square inch; the drop test ensures safety and the tensile strain ensures the necessary carburization and consequent durability.

Alloys for Carriage Bearings.

	English G.W.R.	French.	Italian.
Copper	22	82	—
Tin	67	18	38
Antimony.. ..	11	—	25
Lead	—	—	37
Total ..	100	100	100

SPRINGS.



E^* = Modulus of elasticity = for spring steel 16,000 tons.
S = Ultimate stress, tons per square inch = $E\,e$ = 40.
e = Ultimate extension of fibre say = ·0025.
L = Half length of spring from buckle in inches.
b = Breadth of plates in inches.
t = Thickness of each plate in inches.
n = Number of plates.
W = Total load on spring in tons.

d = Length of offset = $\dfrac{L}{n}$.

v = Deflection of spring in inches per ton of load.
V = Working deflection = $v\,W$.

r = Radius of curve of camber = $\dfrac{E\,t}{2\,S} = 200\,t$; approximately.

Safe working load of spring in tons = $\dfrac{S\,b\,t^2\,n}{3\,L}$; = $\dfrac{13 \cdot 3\,b\,t^2\,n}{L}$.

$$v = \frac{4\,L^3}{E\,b\,t^3\,n}\,; = \frac{L^3}{4000\,b\,t^3\,n};\; n = \frac{L\,W}{13 \cdot 3\,b\,t^2}.$$

Half span of spring from buckle = $\sqrt{(2r - V)\,V}$.

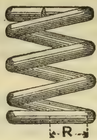
TABLE OF WORKING CAMBER OF SPRINGS.

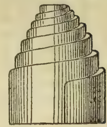
Thickness of plates, ins.	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$
Radius of camber "	50	$62\frac{1}{2}$	75	$87\frac{1}{2}$	100	$112\frac{1}{2}$	125

* E varies according to the quality of the steel from 13,000 to 20,000 tons.

Helical and Volute Springs.

HELICAL. VOLUTE.





E = Modulus of elasticity in tons.
R = Mean radius of spring in inches.
I = Moment of inertia of section of spring.
D = Diameter of spring steel if round in inches.
b = Breadth of rectangular or square section in inches.
d = Depth of rectangular section in inches.
F = Deflection of spring in inches.
T = Modulus of torsion about $\frac{1}{3}$ E.
n = Number of revolutions of spring.
W = Working load, tons.

$$W = \frac{3\,D^3}{R} \text{ for round steel; } = \frac{4 \cdot 72\, b^3}{R} \text{ for square steel.}$$

$$W = \frac{6 \cdot 67\, b^2\, d^2}{R\sqrt{b^2 + d^2}} \text{ for rectangular steel.}$$

$$F = \frac{R^3\, W\, 2\, \pi\, n}{I\, T} = \frac{64\, n\, W\, R^3}{T\, D^4} \text{ for round steel;}$$

$$= \frac{R^3\, W\, 12\, \pi\, n}{T\, b^4} \text{ for square; } = \frac{R^3\, W\, (b^2 + d^2)\, 6\, \pi\, n}{T \,.\, b^3\, d^3}.$$

These formulæ refer to helical springs, but they may be made to apply approximately to volute springs. The deflection of volute springs is, however, not directly proportional to the load, but increases somewhat slowly with heavy pressure. The section of a volute spring should gradually diminish from the base to the apex. The offsets of the volute spring should vary as the cube of the radius R. In conical springs, with constant cross sections of steel, the deflection equals from $\frac{1}{4}$ to $\frac{1}{3}$ that of a cylindrical spring whose radius equals that of the base of the cone.

Railway Carriages.

Dimensions of ordinary narrow-gauge carriages:—

Frame, 17 ft. 11 in. long × 6 ft. 8 in. wide.
Body, 18 ft. long × 7 ft. 4 in. × 6 ft. 2 in. high.
Compartments, each 6 ft. long.
Sides and ends of under framing, 11 × 4.
Transoms, 9 × 3 and 11 × 3.
Framing of body, 3 × $2\frac{1}{2}$ and $2\frac{1}{2}$ × $2\frac{1}{2}$.
Flooring, two thicknesses of $\frac{3}{4}$ boarding, laid diagonally.
Roof, $\frac{3}{4}$ thick on ribs $2\frac{1}{2}$ × $1\frac{3}{4}$, 2 ft. apart.
Width of doors, 1 ft. 11 in. × 5 ft. 5 in. high.
Seats, 1 ft. 6 in. from floor.
Extreme length over buffers, 22 ft.
Wheels, 3 ft. diameter, 9 ft. from centre to centre.
Journals, 6 ft. 4 in. apart.

Ordinary Narrow-gauge Waggons.

	ft.	in.		ft.	in.		ft.	in.	
Open box waggon, body ..	7	6	wide,	16	0	long,	2	0	height of side.
Coal waggon	7	6	"	16	0	"	3	0	"
Coke waggon	7	6	"	16	0	"	4	6	"
Cattle waggon, roofed over ..	7	10	"	16	0	"	6	9	"
Covered goods waggon	7	8	"	16	0	"	5	6	"
Break van	7	2	"	13	6	"	4	6	"
Extreme length over buffers	20	0							

Rolling Stock.

No. of Engines, Carriages, &c., for each 100 Miles of Railway.

	England.	Scotland.	Ireland.
Passenger engines	24	23	13
Goods "	32	28	8
Tank "	8	4	6
Total number of engines	64	55	27
First class carriages	37	34	22
Second "	48	32	17
Third "	43	55	25
Composite and other carriages ..	20	11	12
Total number of carriages	148	132	76
Horse boxes	20	13	9
Carriage trucks	17	11	9
Goods waggons	715	700	223
Mineral and other waggons	1094	980	49
Cattle waggons	95	81	58
Total waggons..	1904	1761	330

WORKING EXPENSES OF RAILWAYS IN GREAT BRITAIN.

	England.	Scotland.	Ireland.
Number of trains per mile open, per annum—			
Passenger	243	180	128
Goods	135	144	19
Total	378	324	147
Mileage of trains per mile open, per annum—			
Passenger	5,685	3558	2937
Goods	4,991	4357	1005
Total	10,676	7915	3942
Expenditure per mile open, per annum—	£	£	£
Maintenance	231	139	65
Locomotive and carriage ..	565	390	199
Traffic charges	400	223	112
Miscellaneous	188	150	61
Rates and duty	113	49	18
Total	1497	951	455
Receipts per mile open, per annum—	£	£	£
Passengers	1511	841	733
Goods	1575	1205	348
Total	3086	2046	1081
Expenditure per train mile—	d.	d.	d.
Maintenance	5·12	4·24	4·03
Locomotive and carriage dept.	12·76	11·71	12·41
Traffic charges	9·05	6·70	6·95
Miscellaneous	4·24	4·39	3·78
Rates and taxes	2·61	1·55	1·16
Total	33·78	28·59	28·33

Comparative Working Expenses of Railways.

	English.	Scotch.	Irish.	American.	Indian.	French.	German.	Australian.
Working expenses per mile per ann. £	1497	951	455	666	—	1200	1000	—
Ditto per train mile in pence	34	28	28	48	56	43	38	—
Cost of fuel per train mile in pence ..	2·9	2·6	3 9	—	—	5·5	4·8	7·3
Construction of line per mile .. .. £	39,000	28,000	15,000	8000	12,000	25,000	17,000	31,000
Maintenance per mile per annum .. £	231	139	65	230	70	—	—	—
Maintenance per train mile in pence	5	4·2	4	12·5	13	3·9	—	—
Proportion of working expenses to receipts, per cent. .	48	46	41	54	42	44	52	72
Number of locomotives per 100 miles	64	55	27	—	29	—	43	—
Number of passenger carriages per ditto	148	132	76	—	77	—	73	—
Number of waggons per ditto	1904	1761	330	—	550	—	670	—

On the railways of Great Britain the proportion of the details of working expenses is as follows:

Maintenance of way .. .. .. = 15 per cent.
Locomotive and carriage department .. .. = 38 "
Traffic charges .. .. = 26 "
Miscellaneous, including police, watching, compensation .. = 14 "
Duty, rates, &c. .. .. = 7 "

Total expenses 100

Working Expenses of Railways in Great Britain—*continued.*

	England.	Scotland.	Ireland.
Receipts per train mile—	*d.*	*d.*	*d.*
Passengers	65·7	58	52·8
Goods	74·5	66	84
Average	69·3	62·35	67·6
Average fare per mile—	*d.*	*d.*	*d.*
1st class	·2	1·77	1·8
2nd class	1·47	1·55	1·35
3rd class	·87	·87	·90

Number of Employés per Mile on the Railways of Great Britain.

Officers, &c.	·13
Clerks	·97
Inspectors, station masters, ticket collectors	·43
Switchmen, gatekeepers, police, porters, &c.	2·76
Draughtsmen, foremen, &c. ..	·17
Drivers and firemen	·81
Platelayers	·92
Labourers	2·94
Artificers	2·39
Guards, breaksmen, &c.	·4
Miscellaneous	·32
Total	12·24
Number of stations per mile ..	·35

Railway Accidents.

'Min. Inst. Civ. Eng.,' vol. xxi., p. 346. (Brunlees.)

Causes of Railway Accidents in Great Britain from 1854 to 1860, inclusive.

Cause.	No. of Accidents.	Per Cent.
Permanent Way—		
Defective construction	118	
Neglect	25	
Total	143	11
Rolling Stock—		
Defective construction	63	
Neglect	27	
Total	90	7
Management—		
Insufficient accommodation	58	
" establishment	61	
Want of engine power	17	
" breaks	65	
" communication between guard and driver	31	
Want of signals	88	
" timepieces	15	
" turn-tables	2	
" punctuality	50	
Insufficient or badly-enforced regulations	198	
Insufficient interval between the trains	70	
Negligence of servants	211	
Speed too great for road	8	
Want of electric telegraph	97	
Total	971	76
Causes not ascertained	70	6

LIFE OF RAILS. (R. Price Williams.)
('Min. Inst. Civ. Eng.,' vols. xxv. and xxvii.)

Iron Rails.	Life of Rails: In Number of Trains.	Life of Rails: In Tons.
Great Northern Railway—		
Rising gradient 1 in 200 ..	119,455	24,702,861
Falling gradient 1 in 200 ..	57,536	11,760,926
" " ..	65,529	13,484,661
" " ..	47,445	9,679,078
" " ..	58,851	12,116,382
Lancashire and Yorkshire—		
Falling gradient 1 in 130 ..	62,399	12,451,784
Slow speed—level	203,112	38,803,128

Value of 1 mile, allowing 569*l.* for old material = 1371*l*

	Tons.	*d.*
Cost per ton per mile with	12,000,000 =	·0274
" "	24,000,000 =	·0137
" "	36,000,000 =	·009½

EXPERIMENTS AT CAMDEN TOWN. (C. P. Sandberg.)

Mark of rail	T.	Y.	H.	E.*	N.
Crushed with tons ..	3,680,000	4,140,000	3,220,000	6,900,000	3,220,000
Worn out with tons ..	5,060,000	5,290,000	5,060,000	8,970,000	5,520,000

Rails marked T, top and bottom formed of No. 2 iron, the remainder of puddle bars.
" Y, same as T, but the pile for the *top slab* of puddle iron, without any No. 2 iron
" H, top slab made of puddle bars *hammered* after the first heat, and *rolled* after the second heat.
" E, the same as H, but *rolled* after the first as well as the second heat.
" N, Pile composed of puddle bars, without any top slab.

* Rails similar to those marked E were laid down on the Great Northern Railway, and had a life of 13,000,000 tons.

Life of Rolling Stock. (R. Price Williams.) ('Min. Inst. Civ. Eng.,' vol. xxx.)

Life in: Train Miles.	Life in: Years.	Locomotive Valuation (Life 30 years).	Net Cost.	Number of Renewals in period of Life.	Cost in period of Life.
			£.		£.
10,000	½	India-rubber pipe	0·26	60	15·7
80,000	4	Painting	8·23	7½	61·8
100,000	5	Brass tubes, steel ferrules, &c...	162·24	6	973·4
120,000	6	Crank-axles, moulds, &c.	51·22	5	256·1
140,000	7	Tires, pressure-gauges, buffer-plank spindles, brass grass, washing-out plugs, &c. ..	156·88	$4\frac{2}{7}$	672·3
200,000	10	Boiler, axle-boxes and caps, brasses, brass valves and siphons, fire-box shell ends, tube-plate and back fire-box, copper recess-plate, &c.	482·38	3	1447·1
300,000	15	Motion cylinders, reversing catch-slide blocks, blast-pipe, ash-pan, outside and inside springs, spring links, spring pins, &c. ..	107·96	2	215·9
340,000	17	Lubricator, shackle, buffer-plank, chains ..	3·18	$1\frac{13}{17}$	5·6
400,000	20	Clack-boxes, balls and clacks, feed-pipes, smoke-box door, &c.	17·45	1½	26·2
600,000	30	Plain axles, wheels, outside cranks, balance-weights, slide-bar brackets and bars, distance-blocks, eccentric-rods and straps, reversing arm, lever and bracket, reversing-rod shaft, quadrant and collar, connecting-rods and straps, bolts, framing, &c., &c. ..	523·07	1	523·1
	10·8	Total	£ 1512·87		£ 4197·2

LIFE OF ROLLING STOCK—*continued.*

Life in Train Miles.	Life in Years.	Tender Valuation (total life taken as 30 years)	Net Cost.	Number of Renewals during Life.	Cost in period of Life.
			£.		£.
10,000	½	Break-blocks, rose-packings, &c.	0·4	60	25·5
60,000	3	Painting, tires, bolts, and nuts for ditto ..	39·9	10	399·3
100,000	5	Oak plank	1·3	6	8·0
200,000	10	Axle-boxes and caps, brasses and pins, &c., wood bottom and packing for tanks	8·0	3	24·1
300,000	15	Springs, buckles, spring pins, trailing buffers, buffer-blocks, springs, &c.	10·9	2	21·8
600,000	30	Axles, wheel-centres, spring links, frame-plates, horn block-stays, bolts, angle-irons, draw-bolts, coupling boxes, foot-plates, &c., break, valve-rods, &c., feed-pipes, hand-rails, &c., &c.	214·6	1	214·6
		£	275·1	£	693·3

Mean Life in Train Miles.	Mean Life in Years.	Summary.	Average cost of Repairs per annum.	Net Cost.	Total Net Cost in period of longest Life, *viz.* 30 years.
			£.	£.	£.
216,280	10·814	Engine	139·9	1512·87	4197·2
238,160	11·908	Tender	23·1	275·19	693·3
		Total	163	1788·06	4890·5

Life of Rolling Stock—*continued.*

VALUE AT GROSS AFTER 30 YEARS.

Engine, 327*l.*; tender, 63*l.*; total, 390*l.*

Average train mileage per engine per year 20,000

AVERAGE OF 12 PRINCIPAL ENGLISH LINES (ENGINE).

No. of engines per mile worked, ·78.
Train mileage per engine per annum, 18,272.
Running expenses per train mile, 5*d*·56.
" " per engine per annum, 426*l.*
Repairs and renewals per train mile, 3*d*·29.
" " per engine per annum, 249*l.*
Money life per engine, 10 years.

LOCOMOTIVE EXPENSES PER TRAIN MILE.

		d.	*d.*
General charges	.. ..		0·4
Running expenses—	Wages	2·12	
	Coal	2·72	
	Water	·23	
	Oil and tallow	·43	
			5·5
Repairs and renewals—	Labour ..	1·55	
	Materials ..	1·75	
			3·3
	Total ..		9·2

REPAIRS AND RENEWALS OF CARRIAGE AND WAGGON STOCK.

	Carriages.	Waggons.
Average cost per vehicle per annum	£22.	£4 10*s.*
Per cent. per annum on cost	$11\frac{1}{4}$	$6\frac{1}{3}$
Cost per train mile	0·68*d.*	1·6
Total life in years	18	18
Mean money life in years	$8\frac{1}{2}$	16

Traction on Roads.

Resistance in lbs. per ton on Different Roads, exclusive of Gravity.

Stone tramway	20 lbs. per ton.
Paved roads	33 ,, ,,
Macadamized roads	44 to 67 ,,
Gravel	150 lbs. ,,
Soft sandy and gravelly ground	210 ,, ,,

Tractive Force of Horses.

Rate in miles per hour	=	2	3	$3\frac{1}{2}$	4	$4\frac{1}{2}$	5
Tractive force exerted by horse in lbs. ..	=	166	125	104	83	62	41

Paved Roads.

Foundation, 1 inch of sand on 12 inches of gravel well punned, in 3 layers; or a layer of hydraulic concrete, 8 inches thick.

Paving of granite, or trap blocks, 4 inches wide, 9 inches deep, 12 inches long.

Dimensions of Roads adopted in Central India ('Roorkee Treatise.')

	Class of Road.			
	1st.	2nd.	3rd.	4th.
	feet.	feet.	feet.	feet.
Width of land in ordinary cases	108	80	72	54
Ditto when land is valuable..	78	62	54	51
Width of roadway..	30	24	20	—
Width between parapets of culverts ..	30	20	18	—
Ditto bridges above 10 feet waterway	20	18	14	—
Width of metalling, moorum foundation	18	15	14	—
Depth of ditto..	1	1	$\frac{3}{4}$	—
Ditto, broken stone	$\frac{1}{2}$	$\frac{1}{2}$	—	—
Maximum gradient, 1 in	25	20	20	18

Roads.

Ordinary English turnpike-roads, 30 feet wide, the centre 6 inches higher than the sides.

4 feet from the centre, $\frac{1}{2}$ inch below the centre.
9 feet from the centre, 2 inches " "
15 feet from the centre, 6 " " "

Footpaths 6 feet wide, inclined 1 inch towards the road.

Side drains, 3 feet below the surface of the road.

Road material: bottom layer, gravel, burnt clay, or chalk, 8 inches deep. Top layer, broken granite not larger than $1\frac{1}{2}$ inch cube, 6 inches deep.

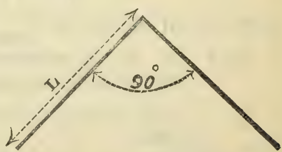
Some use a $2\frac{1}{2}$-inch ring to clear all angles of the cubes for bottom metal, and a 2-inch ring for top metal.

Footpaths: fine gravel, or sifted quarry chippings, 3 inches thick.

Gauging Road-metalling.

Heaped on the side of the road ready for laying.

L = Length of side of gauge in inches.
B = Number of bushels required per lin yard of road.



$L = 12\frac{1}{4}\sqrt{B}$.

The heaped bushel being reckoned at 2700 c. ins.

$L = 17\sqrt{C}$ when C = the number of "cubes" per "line."

A "cube" being = 100 cubic feet.
A "line" " = 100 lineal feet.

Wear of Roads in India

is reckoned at 1 cubic yard of metal per mile for each cart that passes as a daily average over the road.

Useful Memoranda for Hydraulic Calculations.

*1 cubic foot of water .. = 62·425 lbs. = ·557 cwt. = ·028 ton.
1 cubic inch .. .. = ·03612 lb.
1 gallon .. .. .. = 10 lbs. = ·16 cube ft.
1 cube foot of water .. = 6·24 gallons = say $6\frac{1}{4}$ gallons.
1 cwt. of water .. .. = 1·8 cube foot = 11·2 gallons.
1 ton of water .. .. = 35·9 cube feet = 224 gallons.

P = Pressure in lbs. per square inch.
H = Head of water in feet.
V = Theoretical velocity in feet per second.
g = Force of gravity.
$P = H \times \cdot 4335.$ $H = P \times 2\cdot 307.$
Pressure per square foot = H 62·4.

$g = 32\cdot 2.$ $2g = 64\cdot 4.$ $\sqrt{2g} = 8\cdot 025.$

$V = \sqrt{2gH} = 8\cdot 025\sqrt{H}.$

$H = \dfrac{V^2}{2g} = \cdot 0155\,V^2.$ $\dfrac{1}{2g} = \cdot 0155.$

SEA WATER.

1 cube foot of sea water = 64·11 lbs.
Wt. of sea water = 1·027 weight of fresh water.

RAINFALL.

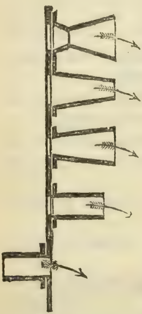
Inches of rainfall × 2,323,200 = cube feet per square mile.
Inches of rainfall × $14\frac{1}{2}$ = millions of gallons per square mile.

* By sale of Gas Act of 1859 the weight of water was fixed at 62·321 lbs. per cubic foot.

Discharge of Water from Orifices, Sluices, &c.

V = Theoretical velocity due to the head of water (from surface of water to centre of orifice). See next page.
A = Area of aperture in square feet.
Q = Quantity discharged in cubic feet
K = Coefficient for different orifices.
E = Velocity of efflux.
$E = V K.$ $Q = E A$

Values of K for Different Orifices.



For vena contracta, orifice at cistern	K = ·97
Converging mouthpiece, angle $13\frac{1}{4}°$, narrow end	= ·94
Diverging 5° — Narrow end ..	= ·92
Diverging 5° — Broad end ..	= ·55
Cylindrical, bore $\frac{1}{2}$ to $\frac{1}{3}$ length	= ·81
" " $\frac{1}{4}$ to $\frac{1}{12}$ "	= ·77
" " $\frac{1}{13}$ to $\frac{1}{24}$ "	= ·73
" " $\frac{1}{25}$ to $\frac{1}{36}$ "	= ·68
Short tube projecting inwards ..	= ·68
Orifice in a thin plate	= ·62
For wide openings whose bottom is on a level with that of the reservoir; for sluices with walls in a line with the orifices; for bridges with pointed piers	= ·96
For narrow openings whose bottom is on a line with that of the reservoir; for abrupt projections and square piers of bridges	= ·86
For sluices without side walls	= ·62

Velocity in feet per second $= 8 \cdot 025 \sqrt{H}$; in feet per minute $= 481 \cdot 5 \sqrt{H}$.

TABLE OF THEORETICAL VELOCITY OF WATER UNDER DIFFERENT HEADS IN FEET PER MINUTE.

Head. Feet.	0	1	2	3	4	5	6	7	8	9	Head. Feet.
0	0	481·5	680·94	833·97	963·0	1076·67	1179·43	1273·93	1361·89	1444·50	0
10	1522·64	1596·94	1667·96	1736·10	1801·63	1864·85	1926·00	1985·27	2042·81	2098·81	10
20	2153·32	2206·52	2258·43	2309·18	2358·87	2407·50	2455·17	2501·97	2547·86	2592·97	20
30	2637·27	2680·90	2723·80	2766·02	2807·63	2848·60	2889·00	2928·87	2968·16	3006·97	30
40	3045·29	3083·09	3120·46	3157·39	3193·89	3230·00	3265·68	3301·02	3335·93	3370·50	40
50	3404·73	3438·58	3472·14	3505·37	3538·30	3570·90	3603·21	3635·23	3667·01	3698·45	50
60	3729·70	3760·61	3791·33	3821·81	3852·00	3882·00	3911·71	3941·27	3970·55	3999·63	60
70	4028·52	4057·17	4085·67	4113·94	4142·01	4169·93	4197·62	4225·16	4252·51	4279·67	70
80	4306·68	4333·50	4360·18	4386·66	4413·04	4439·19	4465·24	4491·14	4516·86	4542·47	80
90	4567·89	4593·22	4618·40	4643·39	4668·34	4693·04	4717·74	4742·25	4766·61	4790·88	90
Head. Feet.	0	1	2	3	4	5	6	7	8	9	Head. Feet.

Head. Feet.	100	200	300	400	500	600	700	800	900	1000	Head. Feet.
0	4815·00	6809·42	8339·82	9630·00	10766·68	11794·29	12739·29	13618·89	14445·00	15226·38	0
25	5383·31	7222·50	8680·39	9926·36	11032·56	12037·50	12964·77	13830·03	14644·24	15415·51	25
50	5897·12	7613·19	9008·05	10214·16	11292·19	12275·89	13186·41	14038·04	14840·84	15602·38	50
75	6369·67	7984·76	9324·20	10494·05	11545·98	12509·76	13404·38	14242·96	15034·84	15787·04	75

TABLE OF PRESSURE IN LBS. PER SQUARE FOOT FOR DIFFERENT HEADS OF WATER.

Head. Feet.	0	1	2	3	4	5	6	7	8	9	Head. Feet.
0	0	62·425	124·850	187·275	249·700	312·125	374·550	436·975	499·400	561·825	0
10	624·25	686·675	749·100	811·525	873·950	936·375	998·800	1061·225	1123·650	1186·075	10
20	1248·50	1310·925	1373·350	1435·775	1498·200	1560·625	1623·050	1685·475	1747·900	1810·325	20
30	1872·75	1935·175	1997·600	2060·025	2122·450	2184·875	2247·300	2309·725	2372·150	2434·575	30
40	2497·00	2559·425	2621·850	2684·275	2746·700	2809·125	2871·550	2933·975	2996·400	3058·825	40
50	3121·25	3183·675	3246·100	3308·525	3370·950	3433·375	3495·800	3558·225	3620·650	3683·075	50
60	3745·50	3807·925	3870·350	3932·775	3995·200	4057·625	4120·050	4182·475	4244·900	4307·325	60
70	4369·75	4432·175	4494·600	4557·025	4619·450	4681·875	4744·300	4806·725	4869·150	4931·575	70
80	4994·00	5056·425	5118·850	5181·275	5243·700	5306·125	5368·550	5430·975	5493·400	5555·825	80
90	5618·250	5680·675	5743·100	5805·525	5867·950	5930·375	5992·800	6055·225	6117·650	6180·075	90
Head. Feet.	0	1	2	3	4	5	6	7	8	9	Head. Feet.

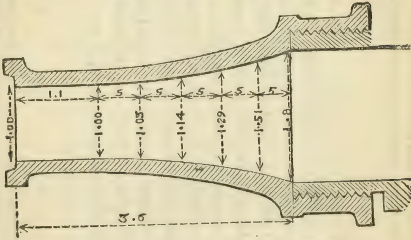
For other heads than those given, alter the decimal point thus: pressure for 24 feet = 1498·2 lbs., for 2·4 = 149·82, for 240 = 14982 lbs. per square foot.

TABLE OF PRESSURE OF WATER, LBS. PER SQUARE INCH.

Head, Feet.	0	1	2	3	4	5	6	7	8	9	Head, Feet.
0	—	·4335	·8670	1·3005	1·7340	2·1675	2·6010	3·0345	3·4681	3·9016	0
10	4·3351	4·7686	5·2021	5·6356	6·0691	6·5026	6·9361	7·3696	7·8031	8·2366	10
20	8·6701	9·1036	9·5372	9·9707	10·4042	10·8377	11·2712	11·7047	12·1382	12·5717	20
30	13·0052	13·4387	13·8722	14·3057	14·7392	15·1727	15·6063	16·0398	16·4733	16·9068	30
40	17·3403	17·7738	18·2073	18·6408	19·0743	19·5078	19·9413	20·3748	20·8083	21·2418	40
50	21·6754	22·1089	22·5424	22·9759	23·4094	23·8429	24·2764	24·7099	25·1434	25·5769	50
60	26·0104	26·4439	26·8774	27·3109	27·7444	28·1780	28·6114	29·0450	29·478	29·9120	60
70	30·3455	30·7790	31·2125	31·6460	32·0795	32·5130	32·9465	33·3800	33·8135	34·2471	70
80	34·6806	35·1141	35·5476	35·9811	36·4146	36·8481	37·2816	37·7151	38·1486	38·5821	80
90	39·0156	39·4491	39·8826	40·3162	40·7497	41·1832	41·6167	42·0502	42·4837	42·9172	90
Head, Feet.	0	1	2	3	4	5	6	7	8	9	Head, Feet.

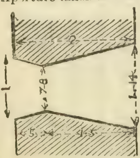
For other heads than those given, alter the decimal point as necessary: for example, pressure per square inch due to 77 feet = 33·38 lbs. per square inch, for 7·7 = 3·338 lbs., for 770 = 333·8.

Proportions of Nozzles. Orifice taken as 1·00.

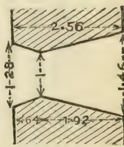


The Proportions of Vena Contracta.

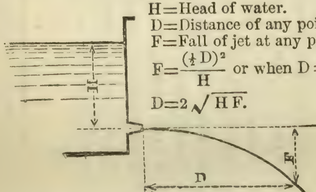
Aperture taken as 1·00.



Neck taken as 1·00.



Theoretical Path described by a Jet of Water issuing from a Lateral Orifice.*



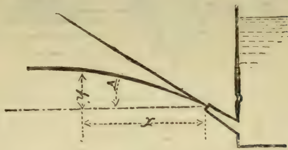
H = Head of water.
D = Distance of any point from orifice.
F = Fall of jet at any point.

$F = \frac{(\frac{1}{2} D)^2}{H}$ or when $D = 2\,H$; $F = H$.

$D = 2\sqrt{H\,F}$.

* The actual path with a good nozzle will be that due to ·95 H for diameters of jet exceeding $\frac{H}{300}$.

Oblique Jets inclined Upwards.

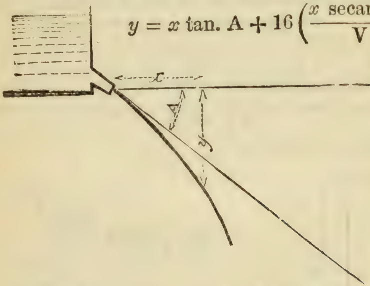


V = Velocity of efflux in feet per second.
A = Angle of jet with horizon.
y = Distance of jet in feet from horizontal line at any point x.

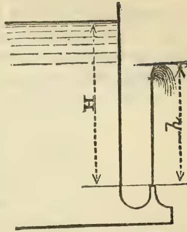
$$y = x \tan. A - 16\left(\frac{x \text{ secant } A}{V}\right)^2.$$

Oblique Jets inclined Downwards.

$$y = x \tan. A + 16\left(\frac{x \text{ secant } A}{V}\right)^2.$$



Note.—These formulæ refer to the theoretical path. The actual path may be assumed nearly as that for a velocity due to the head × ·95 for nozzles exceeding $\frac{1}{300}$th of the head in diameter.



Vertical Jets.

H = Head of water.
h = Height of jet.
D = Diameter of jet.
K = Coefficient varying with ratio of diameter of jet to head.
$h = HK$.

Values of K.

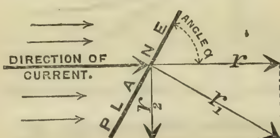
If H = D ×	300	600	1000	1500	1800	2800	3500	4500
K =	·96	·9	·85	·8	·7	·6	·5	·25

Force of Water in Motion.

D = Density of water = 62·4 in fresh; = 64·1 in salt water
g = Gravity = say 32·4.
v = Velocity of current, feet per second.
R = Resistance of a plane normal to the current, lbs. per square foot.
r = Do. Do. of a plane oblique to the current.
r_1 = „ „ „ „ „ and normal to the plane.
r_2 = „ „ „ in direction normal to the current.
α = Angle of obliquity.

$$R = \frac{1{\cdot}86\ D\ v^2}{2g}; = 1{\cdot}8\ v^2 \text{ for fresh water} = 1{\cdot}85\ v^2 \text{ for salt water.}$$

$$r = R\frac{2\sin^2\alpha}{1+\sin^2\alpha};\quad r_1 = \frac{2R}{\text{cosec.}\,\alpha + \sin\alpha};\quad r_2 = R\frac{2\sin\alpha\cos\alpha}{1+\sin^2\alpha}$$



Pressure of Water in Motion

Against a Plane Surface at Right Angles to the Direction of Motion. (Fresh water.)

Velocity of Water.		Pressure lbs. per sq. foot.	Velocity of Water.		Pressure lbs. per sq. foot.	Velocity of Water.		Pressure lbs. per sq. foot.
Miles per hour.	Feet per second.		Miles per hour.	Feet per second.		Miles per hour.	Feet per second.	
1	1·47	3·87	11	16·13	468·51	21	30·80	1708
2	2·93	15·49	12	17·60	557·57	22	32·27	1874
3	4·40	34·85	13	19·07	654·37	23	33·73	2048
4	5·87	61·95	14	20·53	758·91	24	35·20	2230
5	7·33	96·80	15	22·00	871·20	25	36·67	2420
6	8·80	139·39	16	23·47	991·23	26	38·13	2617
7	10·27	189·73	17	24·93	1119·01	27	39·60	2823
8	11·73	247·81	18	26·40	1254·53	28	41·07	3036
9	13·20	313·63	19	27·87	1397·79	29	42·53	3256
10	14·67	387·20	20	29·33	1548·80	30	44·00	3485

Gauging Water.

H = Height of surface of water above sill in feet.
h = Ditto if measured in inches.
V = Velocity of water approaching the sill in feet *per second.*
C = Cubic feet discharged over each foot width of the sill *per minute.*

$$\left.\begin{aligned} C &= 214 \sqrt{H^3} \\ &= 5{\cdot}15 \sqrt{h^3} \end{aligned}\right\} \text{ if the stream above the sill is not in motion.}$$

$$= 214 \sqrt{H^3 + {\cdot}035\, V^2\, H^2} \text{ if in motion.}$$

In gauging, the waste-board must have a thin edge. The height must be measured from the top of the sill, or waste-board, to the level of the surface where it is not affected by the overfall. The waste-board must have a free overfall.

GAUGING WATER—*continued.*

TABLE OF DISCHARGE FROM EACH FOOT OF WIDTH OF SILL IN CUBE FEET PER MINUTE.

Depth of sill.	Decimals of an Inch.									
	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9
in.	c. ft.	c. ft.	c. ft.	c. ft.	c. ft.	c. ft.	c. ft.	c. ft.	c. ft.	c. ft.
0	0·0	·162	·46	·846	1·30	1·823	2·34	3·02	3·68	4·4
1	5·15	5·92	6·75	7·62	8·55	9·42	10·4	11·38	12·41	13·49
2	14·57	15·65	16·79	17·97	19·16	20·34	21·58	22·87	24·1	25·44
3	26·78	28·12	29·56	30·9	32·14	33·78	35·28	36·77	38·16	39·55
4	41·2	42·74	44·29	45·78	47·48	49·13	50·73	52·53	54·07	55·62
5	57·58	59·17	60·92	62·83	64·53	66·33	68·29	70·04	71·89	73·9
6	75·70	77·56	79·46	81·42	83·38	85·23	87·24	89·35	91·26	93·26
7	95·38	97·44	99·54	101·6	103·6	105·8	107·9	109·9	112·1	114·3
8	116·5	118·6	120·9	123·1	125·4	127·6	129·8	133·0	134·4	136·7
9	139	141·3	143·9	146	148·4	150·7	153·2	155·5	157·9	160·4
10	162·8	165·3	167·7	170·2	172·7	175·2	177·7	180·2	182·8	185·3
11	187·9	190·4	193	195·6	198·2	200·8	203·4	206·1	208·7	211·4
12	214·1	216·7	219·4	222·1	224·8	227·5	230·3	233	235·8	238·5

Depth of sill.	Decimals of a Foot.									
	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9
feet.	c. ft.	c. ft.	c. ft.	c. ft.	c. ft.	c. ft.	c. ft.	c. ft.	c. ft.	c. ft.
0	0	6·7	19	34	53	75	99	125	153	183
1	214	246	280	317	357	391	432	472	515	560
2	605	650	697	746	796	845	896	950	1001	1057
3	1112	1168	1228	1284	1335	1401	1465	1527	1585	1643
4	1712	1776	1840	1902	1973	2041	2107	2182	2247	2311
5	2392	2458	2531	2610	2681	2756	2838	2910	2987	3070
6	3145	3222	3302	3883	3464	3541	3625	3712	3792	3875
7	3963	4049	4132	4220	4305	4395	4483	4569	4658	4751
8	4843	4930	5022	5116	5210	5303	5397	5489	5583	5682
9	5778	5872	5970	6067	6165	6264	6364	6463	6563	6664

Delivery of Water in Pipes. (Eytelwein.)

D = Diameter of pipe in inches.
H = Head of water in feet.
L = Length of pipe in feet.
W = Cubic feet of water discharged per minute.

$$W = 4 \cdot 71 \sqrt{\frac{D^5 H}{L}}. \quad D = 0 \cdot 538 \sqrt[5]{\frac{L W^2}{H}}$$

Hawksley's Formula for the Delivery of Water in Pipes.

G = Number of gallons delivered per hour.
L = Length of pipe in yards.
H = Head of water in feet.
D = Diameter of pipe in inches.

$$D = \tfrac{1}{15} \sqrt[5]{\frac{G^2 L}{H}}. \quad G = \sqrt{\frac{(15\,D)^5 H}{L}}.$$

Neville's General Formula

$v = 140 \sqrt{r s} - 11 \sqrt[3]{r s}$ = velocity in feet per second.

r being the hydraulic mean depth in feet and s the sine of the inclination, or the total fall divided by the total length.

In cylindrical pipes, v multiplied by $47 \cdot 124\, d^2$, gives in cubic feet the discharge per minute, or by $293 \cdot 7286\, d^2$ the supply in gallons per minute, d being the diameter of the pipe in feet.

For greater diameters than those given in the Table divide the proposed diameter by 4, and *twice* the velocity opposite to the quotient in the Table will be the required velocity; or the corresponding supply multiplied by 32 will be the approximate supply in gallons per minute.

Flow of Water in Pipes.

Comparison of Formulæ.

R = Mean hydraulic depth in feet = Area ÷ wet perimeter $= \frac{d}{4}$ for circular section of pipe.

$S = \text{Sine of slope} = \frac{H}{L}$.

v = Velocity in feet per second.
d = Diameter of pipe in feet.
L = Length of pipe in feet.
H = Head of water in feet.

Prony $v = 97 \cdot 05 \sqrt{RS} - 0 \cdot 08$;

or $v = 99 \cdot 88 \sqrt{RS} - \cdot 154$.

Eytelwein $v = 50 \sqrt{\frac{dH}{L + 50d}}$;

" $v = 108 \sqrt{RS} - 0 \cdot 13$.

Hawksley $v = 48 \sqrt{\frac{dH}{L + 54d}}$.

Neville $v = 140 \sqrt{RS} - 11 \sqrt[3]{RS}$.

Darcy $v = C \sqrt{RS}$; for value of C, see table.

Diam. of pipe, ins.	½	1	2	3	4	5	6	7	8
Value of C.. ..	65	80	93	99	102	103	105	106	107
Diam of pipe ..	9	10	12	14	16	18	20	22	24
Value of C	108	109	109·5	110	110·5	110·7	111	111·5	111·5

Maximum value of C for very large pipes, 113·3.

Kutter $v = C \sqrt{RS}$; where

$$C = \frac{181 + \frac{\cdot 00281}{S}}{1 + \frac{\cdot 026}{\sqrt{d}}\left(41 \cdot 6 + \frac{\cdot 00281}{S}\right)}.$$

Weisbach $h = \frac{L}{r}\left(\cdot 0036 + \frac{\cdot 0043}{\sqrt{v}}\right)\frac{v^2}{2g}$;

where h = head necessary to overcome the friction in a pipe, and r = the mean radius of the pipe in feet; g = gravity = 32·2.

Darcy $h = \frac{\cdot 02\, L}{d}\left(1 + \frac{1}{12d}\right)\frac{v^2}{29}$.

Cylindrical Pipes.—Table showing the Velocity in Feet per Second, and the Supply in Gallons per Minute, for Long Pipes flowing full, calculated from the Formula $v = 140 \sqrt{rs} - 11 \sqrt[3]{rs}$. (J. T. Hurst.)

Diameter of Pipe in inches.	Head of Water divided by Length of Pipe.								Diameter of Pipe in inches.
	$\frac{1}{1000}$		$\frac{2}{1000}$		$\frac{3}{1000}$		$\frac{4}{1000}$		
	Velocity in feet per second.	Supply in gallons per minute.	Velocity in feet per second.	Supply in gallons per minute.	Velocity in feet per second.	Supply in gallons per minute.	Velocity in feet per second.	Supply in gallons per minute.	
⅜	·173	·05	·278	·08	·363	·10	·436	·13	⅜
½	·212	·11	·336	·17	·436	·22	·522	·27	½
¾	·278	·32	·436	·50	·562	·64	·670	·77	¾
1	·336	·69	·522	1·07	·670	1·37	·798	1·63	1
1¼	·388	1·24	·600	1·91	·770	2·45	·911	2·90	1¼
1½	·436	2·00	·670	3·08	·856	3·93	1·02	4·67	1½
1¾	·481	3·00	·736	4·60	·938	5·86	1·11	6·94	1¾
2	·522	4·26	·798	6·51	1·02	8·29	1·20	9·81	2
2½	·600	7·64	·911	11·62	1·16	14·76	1·37	17·45	2½
3	·670	12·30	1·02	18·66	1·29	23·64	1·52	27·92	3
4	·798	26·03	1·20	39·23	1·52	49·63	1·79	58·53	4
5	·911	46·48	1·37	69·79	1·73	88·14	2·04	103·84	5
6	1·02	74·64	1·52	111·66	1·92	140·83	2·26	165·77	6
7	1·11	111·09	1·66	166·07	2·09	209·22	2·46	246·10	7
8	1·20	156·92	1·79	234·11	2·26	294·70	2·65	346·45	8
9	1·29	212·71	1·92	316·87	2·41	398·58	2·83	468·35	9
10	1·37	279·16	2·04	415·34	2·56	522·08	3·01	613·22	10
11	1·45	356·95	2·15	530·42	2·70	666·39	3·17	782·42	11
12	1·52	446·66	2·26	663·07	2·83	832·63	3·33	977·29	12
15	1·73	793·27	2·56	1174·7	3·21	1473·2	3·76	1727·8	15
18	1·92	1267·5	2·83	1873·4	3·55	2347·2	4·16	2751·4	18
24	2·26	2652·2	3·33	3909·2	4·16	4891·4	4·88	5727·8	24
30	2·56	4698·8	3·76	6911·3	4·71	8638·9	5·51	10109·7	30

CYLINDRICAL PIPES—*continued.*

Diameter of Pipe in inches.	Head of Water divided by Length of Pipe.								Diameter of Pipe in inches.
	$\frac{5}{1000}$		$\frac{6}{1000}$		$\frac{7}{1000}$		$\frac{8}{1000}$		
	Velocity in feet per second.	Supply in gallons per minute.	Velocity in feet per second.	Supply in gallons per minute.	Velocity in feet per second.	Supply in gallons per minute.	Velocity in feet per second.	Supply in gallons per minute.	
⅜	·502	·14	·562	·16	.618	·18	·670	·19	⅜
½	·609	·31	·670	·34	·736	·38	·798	·41	½
¾	·770	·88	·856	·98	·938	1·08	1·02	1·17	¾
1	·911	1·86	1·02	2·08	1·11	2·27	1·20	2·45	1
1¼	1·04	3·31	1·16	3·69	1·27	4·04	1·37	4·36	1¼
1½	1·16	5·44	1·29	5·91	1·41	6·46	1·52	6·98	1½
1¾	1·27	7·91	1·41	8·79	1·55	9·68	1·66	10·38	1¾
2	1·37	11·17	1·52	12·41	1·66	13·56	1·79	14·63	2
2½	1·56	19·85	1·73	22·04	1·82	23·30	2·04	25·96	2½
3	1·73	31·73	1·92	35·21	2·09	38·43	2·26	41·44	3
4	2·04	66·46	2·26	73·68	2·46	80·36	2·65	86·61	4
5	2·31	117·80	2·56	130·52	2·79	142·30	3·01	153·31	5
6	2·56	187·95	2·83	208·16	3·09	226·84	3·33	244·32	6
7	2·79	278·90	3·09	308·76	3·37	335·60	3·62	362·21	7
8	3·01	392·46	3·33	434·35	3·62	473·09	3·90	509·38	8
9	3·21	530·36	3·55	586·82	3·87	639·02	4·16	687·85	9
10	3·40	694·24	3·76	767·92	4·09	833·58	4·41	899·75	10
11	3·59	885·56	3·97	979·39	4·32	1066·1	4·65	1147·2	11
12	3·76	1105·8	4·16	1222·9	4·53	1331·8	4·88	1432·0	12
15	4·26	1956·7	4·71	2159·7	5·12	2349·8	5·51	2527·4	15
18	4·71	3110·0	5·18	3426·1	5·65	3737·0	6·08	4019·3	18
24	5·51	6470·3	6·08	7145·4	6·61	7769·1	7·11	8351·6	24
30	6·22	11415·0	6·86	12601·3	7·50	13772·4	8·02	14720·4	20

CYLINDRICAL PIPES—*continued.*

Diameter of Pipe in inches.	Head of Water divided by Length of Pipe.								Diameter of Pipe in inches.
	$\frac{9}{1000}$		$\frac{1}{100}$		$\frac{2}{100}$		$\frac{3}{100}$		
	Velocity in feet per second.	Supply in gallons per minute.	Velocity in feet per second.	Supply in gallons per minute.	Velocity in feet per second.	Supply in gallons per minute.	Velocity in feet per second.	Supply in gallons per minute.	
$\frac{3}{8}$	·720	·21	·770	·22	1·16	·33	1·47	·42	$\frac{3}{8}$
$\frac{1}{2}$	·856	·44	·911	·46	1·37	·70	1·73	·88	$\frac{1}{2}$
$\frac{3}{4}$	1·09	1·24	1·16	1·33	1·73	1·98	2·18	2·50	$\frac{3}{4}$
1	1·29	2·63	1·37	2·79	2·04	4·15	2·56	5·22	1
$1\frac{1}{4}$	1·47	4·67	1·56	4·96	2·31	7·36	2·90	9·24	$1\frac{1}{4}$
$1\frac{1}{2}$	1·63	7·47	1·73	7·93	2·56	11·75	3·21	14·73	$1\frac{1}{2}$
$1\frac{3}{4}$	1·78	11·10	1·89	11·79	2·79	17·43	3·50	21·84	$1\frac{3}{4}$
2	1·92	15·65	2·04	16·61	3·01	24·53	3·76	30·72	2
$2\frac{1}{2}$	2·18	27·75	2·31	29·45	3·40	43·39	4·26	54·35	$2\frac{1}{2}$
3	2·41	44·29	2·56	46·99	3·76	69·11	4·71	86·39	3
4	2·83	92·51	3·01	98·60	4·41	144·20	5·51	179·73	4
5	3·21	163·69	3·40	173·70	4·99	254·50	6·22	317·08	5
6	3·55	260·81	3·76	277·10	5·51	404·30	6·86	504·05	6
7	3·87	386·57	4·09	408·45	5·99	598·62	7·50	749·83	7
8	4·16	543·49	4·41	575·83	6·44	840·68	8·02	1046·8	8
9	4·44	733·83	4·71	777·50	6·86	1134·1	8·54	1411·6	9
10	4·71	959·88	4·99	1016·9	7·27	1482·3	9·04	1844·3	10
11	4·96	1223·7	5·26	1298·4	7·65	1888·3	9·52	2348·8	11
12	5·18	1522·7	5·51	1617·6	8·02	2355·3	9·97	2928·7	12
15	5·87	2694·9	6·22	2853·8	9·04	4149·7	11·24	5157·0	15
18	6·48	4284·7	6·86	4536·5	10·07	6653·8	12·38	8184·8	18
24	7·58	8900·4	8·02	9421·1	11·63	13664·4	14·43	16958·3	24
30	8·54	15684·5	9·04	16599·0	13·10	23993·0	16·25	29828·1	30

Cylindrical Pipes—continued.

Diameter of Pipe in inches.	Head of Water divided by Length of Pipe.								Diameter of Pipe in inches.
	$\frac{4}{100}$		$\frac{5}{100}$		$\frac{6}{100}$		$\frac{7}{100}$		
	Velocity in feet per second.	Supply in gallons per minute.	Velocity in feet per second.	Supply in gallons per minute.	Velocity in feet per second.	Supply in gallons per minute.	Velocity in feet per second.	Supply in gallons per minute.	
⅜	1·73	·50	1·96	·56	2·18	·62	2·37	·68	⅜
½	2·04	1·04	2·31	1·18	2·56	1·31	2·79	1·42	½
¾	2·56	2·94	2·90	3·33	3·21	3·68	3·50	4·01	¾
1	3·01	6·13	3·40	6·94	3·76	7·68	4·09	8·34	1
1¼	3·40	10·85	3·85	12·27	4·26	13·59	4·63	14·77	1¼
1½	3·76	17·28	4·26	19·57	4·71	21·60	5·12	23·50	1½
1¾	4·09	25·53	4·63	28·95	5·12	31·98	5·57	34·79	1¾
2	4·41	35·99	4·99	40·67	5·51	44·93	5·99	48·87	2
2½	4·99	63·55	5·63	71·79	6·22	79·27	6·76	86·18	2½
3	5·51	101·10	6·22	114·15	6·86	126·01	7·50	137·72	3
4	6·44	210·17	7·27	237·17	8·02	261·70	8·71	284·34	4
5	7·27	370·57	8·20	418·02	9·04	461·08	9·82	500·86	5
6	8·02	588·82	9·04	663·96	9·97	732·18	10·83	795·20	6
7	8·71	870·78	9·82	981·68	10·83	1082·4	11·76	1175·3	7
8	9·36	1222·0	10·55	1377·3	11·63	1518·3	12·63	1648·4	8
9	9·97	1647·4	11·24	1856·4	12·38	2046·2	13·44	2221·3	9
10	10·55	2152·0	11·89	2424·5	13·10	2665·9	14·22	2900·4	10
11	11·10	2740·1	12·49	3082·9	13·78	3401·4	14·96	3691·7	11
12	11·63	3416·1	13·10	3838·9	14·43	4239·6	15·66	4601·1	12
15	13·10	5998·2	14·75	6769·5	16·25	7457·0	17·63	8091·3	15
18	14·43	9539·1	16·25	10738·1	17·89	11826·3	19·41	12830·1	18
24	16·81	19754·1	18·92	22228·8	20·83	24474·3	22·59	26545·4	24
30	18·92	34732·5	21·28	39073·2	23·43	43011·1	25·41	46642·4	30

CYLINDRICAL PIPES—*continued.*

Diameter of Pipe in inches.	Head of Water divided by Length of Pipe.								Diameter of Pipe in inches.
	8/100		9/100		1/10		2/10		
	Velocity in feet per second.	Supply in gallons per minute.	Velocity in feet per second.	Supply in gallons per minute.	Velocity in feet per second.	Supply in gallons per minute.	Velocity in feet per second.	Supply in gallons per minute.	
3/8	2·56	·73	2·74	·79	2·90	·83	4·26	1·22	3/8
1/2	3·01	1·53	3·21	1·64	3·40	1·36	4·99	2·54	1/2
3/4	3·76	4·32	4·01	4·60	4·26	4·89	6·22	7·13	3/4
1	4·41	9·00	4·71	9·60	4·99	10·17	7·27	14·82	1
1¼	4·99	15·89	5·32	16·94	5·63	17·95	8·20	26·13	1¼
1½	5·51	25·27	5·87	26·95	6·22	28·54	9·04	41·50	1½
1¾	5·99	37·41	6·38	39·89	6·76	42·23	9·82	61·35	1¾
2	6·44	52·54	6·86	56·01	7·27	59·29	10·55	86·08	2
2½	7·27	92·64	7·74	98·73	8·20	104·50	11·89	151·53	2½
3	8·02	147·20	8·54	156·85	9·04	165·99	13·10	239·93	3
4	9·36	305·50	9·97	325·41	10·55	344·32	15·26	498·17	4
5	10·55	537·99	11·24	572·99	11·89	606·13	17·18	876·11	5
6	11·63	854·02	12·38	909·42	13·10	959·72	18·92	1389·3	6
7	12·63	1262·1	13·44	1343·7	14·22	1421·2	20·52	2051·3	7
8	13·56	1765·8	14·43	1884·3	15·26	1992·7	22·02	2874·7	8
9	14·43	2384·8	15·36	2538·6	16·25	2684·5	23·43	3871·0	9
10	15·26	3113·5	16·25	3314·2	17·18	3504·5	24·76	5051·3	10
11	16·06	3962·7	17·09	4217·9	18·07	4459·7	26·04	6425·9	11
12	16·81	4938·6	17·89	5256·2	18·92	5557·2	27·25	8004·7	12
15	18·92	8683·1	20·13	9240·3	21·28	9768·3	30·63	14059·7	15
18	20·83	13766·8	22·16	14648·5	23·43	15484·0	33·70	22273·1	18
24	24·24	28477·6	25·79	30296·3	27·25	32018·8	39·17	46016·9	24
30	27·25	50029·4	28·99	53218·5	30·63	56238·9	44·0	80770·7	30

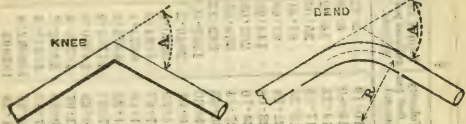
CYLINDRICAL PIPES—*continued.*

Diameter of Pipe in inches.	Head of Water divided by Length of Pipe. $\frac{3}{10}$ Velocity in feet per second.	$\frac{3}{10}$ Supply in gallons per minute.	$\frac{4}{10}$ Velocity in feet per second.	$\frac{4}{10}$ Supply in gallons per minute.	$\frac{5}{10}$ Velocity in feet per second.	$\frac{5}{10}$ Supply in gallons per minute.	$\frac{6}{10}$ Velocity in feet per second.	$\frac{6}{10}$ Supply in gallons per minute.	Diameter of Pipe in inches.
⅜	5·32	1·52	6·22	1·78	7·02	2·01	7·74	2·22	⅜
½	6·22	3·17	7·27	3·71	8·20	4·18	9·04	4·61	½
¾	7·74	8·89	9·04	10·37	10·19	11·69	11·24	12·89	¾
1	9·04	18·44	10·55	21·52	11·89	24·25	13·10	26·66	1
1¼	10·19	32·48	11·89	37·88	13·39	42·67	14·75	47·01	1¼
1½	11·24	51·57	13·10	59·98	14·75	67·70	16·25	74·57	1½
1¾	12·20	76·21	14·22	88·82	16·01	99·99	17·63	110·14	1¾
2	13·10	106·64	15·26	124·54	17·18	140·18	18·92	154·37	2
2½	14·75	188·42	17·18	219·03	19·33	246·46	21·28	271·34	2½
3	16·25	298·28	18·92	347·32	21·28	390·73	23·43	430·11	3
4	18·92	617·47	22·02	718·66	24·76	808·21	25·25	824·14	4
5	21·28	1085·4	24·76	1262·8	27·84	1419·8	30·63	1561·7	5
6	23·43	1720·4	27·25	2001·2	30·63	2248·9	33·70	2474·8	6
7	25·41	2539·4	29·55	2953·2	33·21	3319·2	36·53	3651·1	7
8	27·25	3557·6	31·67	4134·9	35·60	4647·9	39·17	5113·0	8
9	28·99	4789·7	33·70	5568·3	37·87	6256·8	41·65	6881·1	9
10	30·63	6246·9	35·60	7262·3	40·01	8161·0	44·00	8974·3	10
11	32·20	7947·9	37·41	9234·4	42·00	10365·4	46·24	11411·6	11
12	33·70	9899·2	39·17	11504·2	44·00	12923·0	48·38	14209·8	12
15	37·87	17380·0	44·0	20192·7	49·42	22679·2	54·33	24932·9	15
18	41·65	27524·2	48·38	31972·0	54·33	35903·4	59·72	39465·9	18
24	48·38	56839·1	56·18	66005·2	63·07	74102·4	69·32	81442·6	24
30	54·33	99731·6	63·07	115785	70·80	129971	77·80	142825	30

CYLINDRICAL PIPES—*continued.*

Diameter of Pipe in inches.	Head of Water divided by Length of Pipe.								Diameter of Pipe in inches.
	$\frac{7}{10}$		$\frac{8}{10}$		$\frac{9}{10}$		1		
	Velocity in feet per second.	Supply in gallons per minute.	Velocity in feet per second.	Supply in gallons per minute	Velocity in feet per second.	Supply in gallons per minute.	Velocity in feet per second.	Supply in gallons per minute.	
$\frac{3}{8}$	8·42	2·41	9·04	2·59	9·63	2·76	10·19	2·92	$\frac{3}{8}$
$\frac{1}{2}$	9·82	5·01	10·55	5·38	11·24	5·73	11·89	6·06	$\frac{1}{2}$
$\frac{3}{4}$	12·20	14·00	13·10	15·00	13·93	15·98	14·75	16·92	$\frac{3}{4}$
1	14·22	29·00	15·26	31·14	16·25	33·14	17·18	35·04	1
$1\frac{1}{4}$	16·01	51·02	17·18	54·76	18·28	58·28	19·33	61·61	$1\frac{1}{4}$
$1\frac{1}{2}$	17·63	80·91	18·92	86·83	20·13	92·40	21·28	97·68	$1\frac{1}{2}$
$1\frac{3}{4}$	19·13	119·48	20·52	128·21	21·84	136·42	23·08	144·20	$1\frac{3}{4}$
2	20·52	167·45	22·02	179·67	23·43	191·16	24·76	202·05	2
$2\frac{1}{2}$	23·08	294·29	24·76	315·71	26·34	335·86	27·84	354·95	$2\frac{1}{2}$
3	25·41	466·42	27·25	500·29	28·99	532·18	30·63	562·22	3
4	29·55	964·31	31·67	1033·7	33·70	1099·9	35·60	1162·0	4
5	33·21	1692·6	35·60	1815·6	37·87	1931·1	40·01	2040·2	5
6	36·53	2682·4	39·17	2876·1	41·65	3058·2	44·00	3230·8	6
7	39·59	3957·0	42·44	4242·3	45·13	4510·7	47·67	4764·9	7
8	42·44	5540·9	45·50	5940·0	48·33	6315·4	51·10	6671·1	8
9	45·13	7456·4	48·33	7993·0	51·44	8499·2	54·33	8975·8	9
10	47·67	9724·4	51·10	10423·5	54·33	11081·3	57·33	11704·2	10
11	50·10	12364·4	53·70	13252·8	57·08	14088·5	60·29	14880·0	11
12	52·40	15391·1	56·18	16501·3	59·72	17540·4	63·07	18525·6	12
15	58·85	27009·8	63·07	28946·2	67·04	30767·7	70·80	32492·7	15
18	64·52	42641·5	69·32	45811·5	73·67	48690·4	77·80	51416·9	18
24	75·07	88204·4	80·44	94508·9	85·49	100438·1	90·26	106052·8	24
30	84·25	154668	90·26	165708	95·92	176090	101·26	185902	30

Friction of Knees and Bends.



A = Angle of bend or knee with forward line of direction.
V = Velocity of water in feet per second.
R = Radius of centre line of bend.
r = Radius of bore of pipe (or ½ diameter).
K = Coefficient for angles of knees.
L = Coefficient for curvature of bends.
H = Head of water in feet necessary to overcome the friction of the bend or knee.

or knees, $H = \cdot 0155\, V^2 K$.

The value of K is as follows for different angles:—

A° =	20°	40°	60°	80°	90°	100°	120°
K =	·046	·139	·364	·74	·98	1·26	1·86

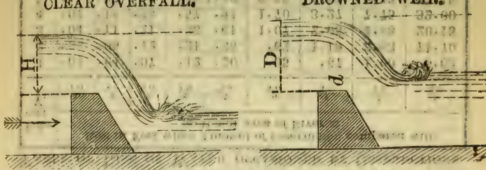
For bends, $H = \cdot 0155\, V^2 \left(\frac{A}{180} L\right)$.

Values of L with various ratios of the radius of bend to radius of bore:—

When $\frac{r}{R}$ =	·1	·2	·3	·4	·5	·6	·7	·8	·9	1·0
In circular section L	·131	·138	·158	·206	·294	·44	·66	·98	1·4	2·0
In rectangular " L	·124	·135	·18	·25	·4	·64	1·01	1·55	2·3	3·2

Rise of Water caused by Weirs in Rivers.

CLEAR OVERFALL. DROWNED WEIR.



W = Quantity of water in cubic feet per second passing over the weir.
B = Breadth of weir in feet.
H = Height of water above the top of the weir.
D = Height of water above the top of the weir in a drowned weir.
d = Level of tail water above top of weir in a drowned weir.

$$H = \sqrt[3]{\frac{W^2}{7\,B^2}} \text{ approximately.}$$

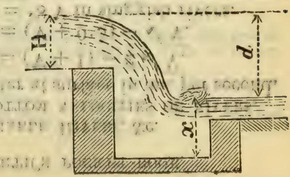
$D = H + d$ as a rough approximation.

$= (H + d) - d\left(1 - \frac{1 \cdot 25\, d}{H}\right)$ as a nearer approximation.

Depth of the Water Cushion for Weirs. (Dyas.)

d = Depth of fall from surface to surface.
H = Height of water over top of weir.
x = Depth of water cushion.

$x = H + \sqrt[3]{H}\,\sqrt{d}.$



Navigable Rivers, &c.

Surface and Bottom Velocities of Rivers.

V = Velocity of water at surface in ins. per second.

Velocity at bottom $= (V + 1) - 2\sqrt{V}$.

Mean velocity .. $= (V + 0 \cdot 5) - \sqrt{V}$.

$= \cdot 8\,V$ in sluggish rivers.

Surface.	Bottom.	Mean.	Surface	Bottom.	Mean.	Surface	Bottom.	Mean.
4	1	2·5	36	25	30·5	68	52·5	60·2
8	3·3	5·6	40	28·3	31·1	72	56·0	64·0
12	6	9	44	31·7	37·8	76	59·5	67·7
16	9	12·5	48	35·1	41·5	80	63·1	71·5
20	12	16	52	38·5	45·2	84	66·6	75·3
24	15	19·5	56	42	49	88	70·2	79·1
28	18·4	23·2	60	45·5	52·7	92	73·7	82·8
32	21·6	26·8	64	49	56·5	100	81	90·5

Obstructions in Rivers.

V = Velocity of river previous to obstruction in feet per second.

A = Sectional area of river unobstructed in feet.

a = " " at obstruction in ft.

R = Rise of water caused by the obstruction in ft.

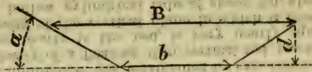
$$R = \left(\frac{V^2}{58 \cdot 6} + 0 \cdot 05\right)\left(\left(\frac{A}{a}\right)^2 - 1\right).$$

Table of Rise of Water occasioned by Obstructions.

Velocity. V.	Rise in Feet when Amount of Obstruction compared with Sectional Area of River =								
	$\frac{1}{10}$	$\frac{2}{10}$	$\frac{3}{10}$	$\frac{4}{10}$	$\frac{5}{10}$	$\frac{6}{10}$	$\frac{7}{10}$	$\frac{8}{10}$	$\frac{9}{10}$
1	·01	·04	·07	·12	·20	·35	·67	1·60	6·63
2	·03	·06	·12	·21	·35	·62	1·19	2·83	11·70
3	·04	·11	·21	·36	·61	1·07	2·05	4·88	20·15
4	·07	·18	·33	·57	·97	1·70	3·27	7·75	32·00
5	·11	·27	·50	·85	1·43	2·50	4·81	11·43	47·18
6	·15	·37	·69	1·18	1·99	3·48	6·71	15·93	65·75

Velocity caused by any obstruction $= \dfrac{1 \cdot 1\,A\,V}{a}$.

TABLE OF PROPORTIONS OF CHANNELS IN TERMS OF THEIR AREA, A. (P = Wetted perimeter.)



Angle of Slope a.	Slope.	Depth. d.	Top. B.	Bottom. b.	$\frac{P}{A}\sqrt{A}$.
90°	Vertical.	$\cdot 707\sqrt{A}$	$1\cdot 414\sqrt{A}$	$1\cdot 414\sqrt{A}$	2·828
60°	·577 to 1	$\cdot 76\sqrt{A}$	$1\cdot 755\sqrt{A}$	$\cdot 877\sqrt{A}$	2·632
45°	1 to 1	$\cdot 74\sqrt{A}$	$2\cdot 092\sqrt{A}$	$\cdot 613\sqrt{A}$	2·704
36° 52′	$1\frac{1}{3}$ to 1	$\cdot 707\sqrt{A}$	$2\cdot 537\sqrt{A}$	$\cdot 471\sqrt{A}$	2·818
30°	1·73 to 1	$\cdot 664\sqrt{A}$	$2\cdot 656\sqrt{A}$	$\cdot 356\sqrt{A}$	3·012
26° 34′	2 to 1	$\cdot 636\sqrt{A}$	$2\cdot 844\sqrt{A}$	$\cdot 3\sqrt{A}$	3·144
Semi-circle.	..	$\cdot 798\sqrt{A}$	$1\cdot 596\sqrt{A}$	..	2·507

KUTTER'S FORMULA FOR DISCHARGE OF WATER IN CHANNELS.

C = Coefficient of mean velocity.
v = Mean velocity, feet per second.
R = Mean hydraulic radius.
S = Sine of inclination of water surface or fall in a length of 1.
n = Coefficient dependent on the lining of the channel.
a, r, and m = Constants. $a = 41\cdot 6$; $r = 1\cdot 811$; $m = \cdot 00281$.

$$C = \frac{a + \frac{r}{n} + \frac{m}{S}}{1 + \left(a + \frac{m}{S}\right)\frac{n}{\sqrt{R}}}\,; \quad v = C\sqrt{RS}.$$

$n = \cdot 009$ for well-planed timber.
$= \cdot 010$ for cement plaster.
$= \cdot 011$ for cement and sand plaster.
$= \cdot 012$ for unplaned timber.
$= \cdot 013$ for ashlar and brick-work.
$= \cdot 017$ for rubble.

$n = \cdot 02$ for canals, fine gravel.
$= \cdot 025$ for rivers in perfect order.
$= \cdot 03$ for rivers in moderate order.
$= \cdot 035$ for rivers in bad order.*

* Overgrown and strewed with stones or detritus.

DISCHARGE OF CHANNELS. (Bazin.)

r = Mean hydraulic depth in feet.
s = Fall of water surface in any distance divided by that distance.
v = Maximum surface velocity in feet per second.
V = Mean velocity in feet per second.
K = Coefficient—depending upon character of bed.
C = Coefficient of discharge.

$K_1 = \sqrt{1 \div \cdot 0000045 \left(10 \cdot 16 + \frac{1}{r}\right)}$ for fine plaster sides and bed.

$K_2 = \sqrt{1 \div \cdot 000013 \left(4 \cdot 354 + \frac{1}{r}\right)}$ for cut stone or brickwork.

$K_3 = \sqrt{1 \div \cdot 00006 \left(1 \cdot 219 + \frac{1}{r}\right)}$ rubble masonry.

$K_4 = \sqrt{1 \div \cdot 00035 \left(\cdot 2438 + \frac{1}{r}\right)}$ earth.

$$C = \frac{K}{K + 25 \cdot 3}.$$

$V = K \sqrt{rs} = Cv$ when r exceeds 20.

r	1	2	4	6	8	10	15	20
K_1	141	144	146	147	147	147	147	147
K_2	118	124	123	129	130	130	130	131
K_3	87	98	106	110	111	112	114	114
K_4	48	62	76	84	88	91	96	98
C_1	·85	·85	·85	·85	·85	·85	·85	·85
C_2	·82	·83	·83	·84	·84	·84	·84	·84
C_3	·77	·79	·81	·81	·81	·82	·82	·82
C_4	·65	·71	·75	·77	·78	·78	·79	·80

DETERMINATION OF MEAN VELOCITY OF WATER IN CANALS.

Major Cunningham has established by experiment that the actual velocity of a floating thin vertical rod reaching from the surface nearly to the bed, is very nearly equal to the mean velocity of the vertical plane in which it moves. The float is a hollow cylindrical tube of sheet tin, about 1 inch diameter, loaded with rod iron at the bottom, so that the top projects 2 or 3 inches above the surface of the water: the whole is hermetically sealed and painted.

FLOW OF RIVERS, &c.

FORMULÆ DEDUCED FROM EXPERIMENTS ON THE MISSISSIPPI.

A = Area of cross-section.
P = Length of wetted perimeter.
W = Width of river at surface of water.

$$R = \text{Mean radius} = \frac{A}{P + W}.$$

$$D = \text{Hydraulic mean depth} = \frac{A}{P}.$$

$$s = \text{Slope of channel; or } \frac{\text{fall}}{\text{length}}.$$

V = Mean velocity.

$$K = \frac{1 \cdot 69}{\sqrt{D + 1 \cdot 5}}.$$

$$V = \left[\sqrt{\cdot 0064\, K + (195\, R \sqrt{s})^{\frac{1}{2}}} - \cdot 08 \sqrt{K}\right]^2$$

for a channel with rectangular cross-section.

$$V = \left[\sqrt{\cdot 0081\, K + (225\, R \sqrt{s})^{\frac{1}{2}}} - \cdot 09 \sqrt{K}\right]^2$$

for a river channel.

$$V = \left[\sqrt[4]{225\, R \sqrt{s}} - \cdot 0388\right]^2$$

for rivers whose mean radius exceeds 12 or 15 feet.

FLOOD DISCHARGE OF RIVERS IN INDIA.

(Colonel Dickens' formula.) Bengal.

D = Maximum flood discharge in cube feet per second.
L = Length of river miles.
M = Square miles of drainage area.

$$D = 825\, M^{\frac{3}{4}}.$$

In Madras, $D = \frac{1300\, M}{\sqrt[3]{L^2}}$; (Benge) $= C \sqrt[3]{M^2}$; (Ryves).

$C = 450$ within 15 miles of the sea; $= 562 \cdot 5$ between 15 and 100 miles; $= 675$ for limited areas near hills.

Discharge of Water in Open Channels.

V = Mean velocity in feet per second.
D = Mean hydraulic depth = area ÷ wet perimeter.
S = Slope or length of channel to fall of 1.
K = Coefficient. (See Table below.)
A = Area of channel.
Q = Quantity of water delivered per second.

$$V = \sqrt{\frac{K\,D}{S}}. \qquad Q = A\,V.$$

Description of Channel.	Values of K for Velocities: Less than 4 feet per second.	Values of K for Velocities: More than 4 feet per second.
Brickwork	8800	8500
Earth	7200	6800
Shingle	6400	5900
Rough, with boulders ..	5300	4700

In very large channels, rivers, &c., the description of the channel affects the result so slightly that it may be practically neglected, and K assumed = from 8500 to 9000.

Efflux of Water under Variable Pressure.

H = Head of water in feet.
V = Effective mean velocity of efflux in cubic feet per second.
T = Time of discharge in seconds.
A = Horizontal area of vessel in feet.
a = Area of discharging orifice in feet.
K = Coefficient for orifice.

$$V = 4\,a\,K\sqrt{H}. \qquad T = \frac{A\,H}{4\,a\,K\sqrt{H}}.$$

FLOW OF WATER IN CHANNELS. Comparison of Formulæ.

R = Mean hydraulic depth in feet = Area of cross-section ÷ wetted perimeter. S = Sine of slope.

v = Velocity in feet per second.

Young's coefficient, $v = 84 \cdot 3 \sqrt{RS}$; Leslie for small streams, $v = 68 \cdot 8 \sqrt{RS}$;

Eytelwein, $v = 93 \cdot 4 \sqrt{RS}$; Beardmore, $v = 94 \cdot 2 \sqrt{RS}$;

Leslie for large streams, D'Aubisson, Downing, $v = 100 \sqrt{RS}$;

Prony, $v = 103 \sqrt{RS} - 0 \cdot 236$; Weisbach, $v = 99 \cdot 92 \sqrt{RS} - \cdot 0154$;

Girard, $v = 102 \cdot 8 \sqrt{RS} - 1 \cdot 64$; St. Venant, $v = 106 \sqrt[21]{(RS)^{11}}$;

Ellet, $v = 0 \cdot 64 \sqrt{dh} + \cdot 04\, dh$, where d = the maximum depth of the stream and h = fall of water per mile;

Neville, $v = 93 \sqrt{RS} - \cdot 02$; Provis, $v = 60 \sqrt{RS} + 120 \sqrt[3]{(RS)^2}$;

Kutter, $v = C \sqrt{RS}$ (see Kutter's formula for value of C);

Bazin, $v = C \sqrt{RS}$ (see Bazin's „ „ „ „);

Humphreys and Abbott, $v = C \sqrt{RS}$, where $C = \dfrac{5 \cdot 86\, x}{\sqrt[4]{S}}$

and x varies from $\cdot 85$ to $\cdot 97$;

Dubuat, $$v = \frac{88 \cdot 51 (\sqrt{R} - \cdot 03)}{\sqrt{\frac{1}{S}} - \text{hyp. log.} \sqrt{\frac{1}{S}} - 1 \cdot 6} - \cdot 084 (\sqrt{R} - \cdot 03);$$

Young, $$v = \sqrt{\frac{RS}{3A} + \left(\frac{B}{12A}\right)^2} - \frac{B}{12A}, \text{ where}$$

$$A = \cdot 0000001 \left(413 + \frac{1 \cdot 5625}{R} - \frac{90}{3R + 8} - \frac{15}{4R + \cdot 03}\right), \text{ and}$$

$$B = \cdot 0000001 \left\{\frac{900 R^2}{R^2 + 0 \cdot 5} + \frac{1}{\sqrt{3R}}\left(271 \cdot 25 + \frac{6 \cdot 88}{R} + \frac{\cdot 0001146}{R^2}\right)\right\}.$$

COMPARATIVE RESULTS OF FORMULÆ IN RIVERS OF VARIOUS MAGNITUDE. (Stevenson.)

Actual discharge, feet per second.	Leslie.	Dubuat.	Robinson.	Ellet.	Eytelwein.	Downing.	Girard.	Prony.	Missisippi.
24·22	28 04	32·5	36·9	46·4	—	41·23	—	—	—
2423	2083	2987	2560	2033	—	27·69	—	—	—
31864	—	16931	—	—	23389	25031	22491	22357	39938
1 15 millions.	—	·675	—	·770	·908	·972	1·218	·943	1·49

Time Employed in Filling and Emptying Cisterns when the Supply and Consumption are going on at the same Time.

Q = Supply of water into cistern in cube feet per minute.

q = Consumption of ditto from cistern in cube feet per minute.

C = Contents of cistern in cube feet.

T = Time required for filling cistern in minutes.

t = Ditto for emptying ditto in minutes.

$$T = \frac{C}{Q - q} \qquad t = \frac{C}{q - Q}.$$

Time Required to Empty Canal Locks, &c.

A = Area of lock in ft. a = Area of sluice in ft.

H = Head of water in feet.

T = Time required in seconds. $\quad T = \dfrac{\cdot 4\, A\, H}{a \sqrt{H}}.$

This is under the supposition that the sluice is constantly submerged; so that its entire area is available throughout.

The coefficient for lock sluices has been assumed to be about ·6.

Maximum Power of a Horse on Canals at Different Speeds.

V = Velocity in miles per hour.

H = Duration of work in hours per day.

L = Total load drawn by one horse on canal in tons

V.	H.	L.	V.	H.	L.
$2\frac{1}{2}$	$11\frac{1}{2}$	520	6	2	30
3	8	243	7	$1\frac{1}{2}$	19
$3\frac{1}{2}$	$5\frac{9}{10}$	153	8	$1\frac{1}{8}$	13
4	$4\frac{1}{2}$	102	9	$\frac{9}{10}$	9
5	$2\frac{9}{10}$	52	10	$\frac{3}{4}$	$6\frac{1}{2}$

CANALS.

	Ordinary dimensions.	Dimensions for special traffic in feet.
Depth of water	5 feet	$= D + 1 \cdot 5$ foot.
Width at surface	40 feet	$= 3B + 3(D + 1 \cdot 5)$.
„ bottom	25 feet	$= 3B$.

LOCKS.

Clear width .. $= B + 1$ foot.
„ length .. $= L + 1$ foot.
Depth, minimum, $= D + 1\frac{1}{2}$ foot.
Where D = Maximum draught of boat in feet;
B = Extreme breadth of boat in feet;
L = Extreme length of boat in feet, including rudder.

Ordinary canal lock, 75 feet long, 8 feet broad, 5 feet depth over sill.

Loss of water in canals, exclusive of water expended in passing boats through locks:—
Let A = Total area of surface of canal in sq. yds.
L = Loss of water in cubic feet per day.

For England .. $L = 1 \cdot 5 A + 15{,}000$.

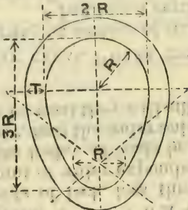
Cubic contents of lock, less the displacement, equal the amount of water expended in passing a boat through the lock. If boats be locked up and down alternately, half the water only will be used; if double locks be used they will effect a saving of half the water.

ORDINARY CANAL "OVER BRIDGES."

Width of waterway at surface of water 13 ft.
„ „ 5 feet below surface 11 „
Headway above surface .. .. 11 „
Semicircular arch .. .. 20 „ span.
Width of towing path .. .. 6 „

AREAS OF SEWERS. (C. E. Hawkins.)

Proportion of height to extreme width inside 3 : 2.



R = Radius of upper circle; T = Thickness of brickwork.
Area of sewer $= 4{\cdot}5941\ R^2$; area of brickwork $= 3{\cdot}1416\ T\ (T + 2{\cdot}5242\ R)$.

TABLE.

Size of Sewer. Inches.	Area of Sewer. Sq. Ft.	Cube Yards of Brickwork per Yard Run.		Size of Sewer. Inches.	Area of Sewer. Sq. Ft.	Cube Yards of Brickwork per Yard Run.	
		4½ in. Work.	9 in. Work.			9 in. Work.	13½ in. Work.
12×18	1·150	·214	·527	42× 63	14·087	1·353	2·176
14×21	1·565	·242	·582	44× 66	15·461	1·408	2·259
16×24	2·044	·269	·637	46× 69	16·898	1·463	2·342
18×27	2·587	·297	·692	48× 72	18·400	1·518	2·424
20×30	3·194	·324	·747	50× 75	19·965	1·573	2·507
22×33	3·865	·352	·802	52× 78	21·594	1·628	2·589
24×36	4·600	·379	·857	54× 81	23·287	1·683	2·672
26×39	5·400	·407	·912	56× 84	25·044	1·738	2·755
28×42	6·261	·434	·967	58× 87	26·865	1·793	2·837
30×45	7·187	·462	1·022	60× 90	28·750	1·848	2·920
32×48	8·178	·490	1·077	62× 93	30·699	1·903	3·002
34×51	9·232	·517	1·132	64× 96	32·711	1·958	3·085
36×54	10·350	·545	1·188	66× 99	34·788	2·014	3·168
38×57	11·532	·572	1·243	68×102	36·928	2·069	3·250
40×60	12·778	·600	1·298	70×105	39 132	2·124	3·333
				72×108	41 400	2·179	3·415

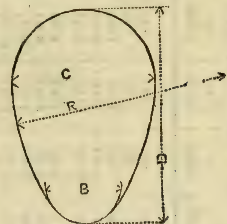
SEWERS.

Flow of Water in Sewer.

x = Area of sewer ÷ the wetted perimeter in ft.
f = Fall in feet per mile.
V = Velocity in feet per minute.
A = Area in square feet.
C = Cubic feet of water delivered per minute.

$$V = 55 \sqrt{x \times 2f}.$$
$$C = V \times A.$$

Egg-shaped Sewer.



Internal Dimensions.

Let B = Diameter of bottom of sewer.
C = " top "
R = Radius of sides "
D = Depth of sewer

$$B = \frac{D}{3}. \qquad C = \frac{2\,D}{3}. \qquad R = D.$$

When D is less than 6 feet the brickwork is generally 9 inches thick.

Above 6 feet, and under 9 feet, brickwork 14 inches thick.

Egg-shaped Sewers. (J. T. Hurst.)

Table showing the discharge in cubic feet per second when the diameter of the larger circle C and the inclination are given, the sewer flowing two-thirds full, calculated from the formula

$Q = 35\sqrt{d^5 \frac{f}{l}}$, d being the diameter C in feet.

Diameter in feet and inches.		Fall Divided by Length.									
		$\frac{1}{10,000}$	$\frac{2}{10,000}$	$\frac{3}{10,000}$	$\frac{4}{10,000}$	$\frac{5}{10,000}$	$\frac{6}{10,000}$	$\frac{7}{10,000}$	$\frac{8}{10,000}$	$\frac{9}{10,000}$	$\frac{1}{1000}$
′	″										
	9	·17	·24	·30	·34	·38	·42	·45	·48	·51	·54
1	0	·35	·49	·61	·70	·78	·86	·93	·99	1·05	1·11
1	3	·61	·86	1·06	·22	1·37	1·50	1·61	1·73	1·83	1·93
1	6	·96	1·36	1·67	1·93	2·16	2·36	2·55	2·73	2·89	3·05
1	9	1·42	2·01	2·46	2·84	3·17	3·47	3·75	4·01	4·25	4·48
2	0	1·98	2·80	3·43	3·96	4·43	4·85	5·24	5·60	5·94	6·26
2	3	2·66	3·76	4·60	5·32	5·94	6·51	7·03	7·52	7·93	8·40
2	6	3·46	4·89	5·99	6·92	7·73	8·47	9·15	9·78	10·38	10·94
2	9	4·39	6·21	7·60	8·78	9·81	10·75	11·61	12·41	13·17	13·88
3	0	5·46	7·72	9·45	10·91	12·20	13·36	14·44	15·43	16·37	17·25
3	6	8·02	11·34	13·89	16·04	17·94	19·65	21·22	22·69	24·06	25·37
4	0	11·20	15·84	19·40	22·40	25·04	27·43	29·53	31·68	33·60	35·42
4	6	15·03	21·26	26·04	30·07	33·62	36·83	39·78	42·52	45·10	47·54
5	0	19·57	27·67	33·89	39·13	43·75	47·93	51·77	55·34	58·70	61·87

Egg-shaped Sewers—*continued.*

Diameter in feet and inches.		Fall Divided by Length.												
		$\frac{2}{1000}$	$\frac{3}{1000}$	$\frac{4}{1000}$	$\frac{5}{1000}$	$\frac{6}{1000}$	$\frac{7}{1000}$	$\frac{8}{1000}$	$\frac{9}{1000}$	$\frac{1}{100}$	$\frac{2}{100}$	$\frac{3}{100}$	$\frac{4}{100}$	$\frac{5}{100}$
′	″													
	9	·76	·95	1·08	1·21	1·32	1·43	1·52	1·62	1·70	2·41	2·95	3·41	3·81
1	0	1·57	1·92	2·21	2·47	2·71	2·93	3·13	3·32	3·50	4·95	6·06	7·00	7·83
1	3	2·73	3·35	3·87	4·32	4·74	4·91	5·47	5·80	6·11	8·65	10·59	12·23	13·67
1	6	4·31	5·28	6·10	6·82	7·47	8·07	8·63	9·15	9·64	13·64	16·71	19·29	21·57
1	9	6·34	7·77	8·97	10·03	10·98	11·86	12·68	13·45	14·18	20·05	24·56	28·36	31·71
2	0	8·85	10·84	12·52	14·00	15·34	16·56	17·71	18·78	19·80	28·00	34·29	39·60	44·27
2	3	11·89	14·56	16·81	18·79	20·59	22·24	23·78	25·21	26·58	37·59	46·03	53·16	59·43
2	6	15·47	18·94	21·88	24·46	26·79	28·94	30·94	32·81	34·59	48·92	59·91	69·18	77·34
2	9	19·63	24·09	27·76	31·04	34·00	36·72	39·26	41·67	43·89	62·07	76·03	87·79	98·15
3	0	24·40	29·88	34·51	38·58	42·26	45·65	48·80	51·76	54·56	77·16	94·50	109·1	122·0
3	6	35·87	43·93	50·73	56·72	62·13	67·11	71·74	76 10	80·21	113·4	138·9	160·4	179·4
4	0	50·09	61·34	70·83	79·20	86·75	93·71	100·2	106·3	112·0	158·4	194·0	224·0	250·4
4	6	67·24	82·35	95·09	106·3	116·5	125·8	134·5	146·6	150·3	212·6	260·4	300·7	336·2
5	0	87·50	107·2	123·7	138·3	151·6	163·7	175·0	185·6	195·7	276·7	338·9	391·3	437·5

Note.—Five-sevenths of the quantity given in the above Table will equal the discharge from Cylindrical Pipes of the same diameter when flowing two-thirds full.

Waves.

A wave may travel without force to maintain its motion, provided it be long in proportion to the depth of the fluid.

1. When the length of a wave is not greater than the depth of the water, the velocity of the wave depends (sensibly) only on its length, and is proportional to the square root of its length.

2. When the length is not *less* than 1000 times the depth of the water, the velocity depends only on the depth, and is the same as the velocity which a free body would acquire by falling through a height = half the depth of the water.

3. For intermediate proportions, the velocity can only be obtained by a general equation. Under no circumstances does an unbroken wave exceed 30 or 40 feet in height. A wave breaks when its height above the general level of the water is equal to the general depth.—*Prof. Airey*, 'Encyclop. Metrop.,' "Tides."

V = Velocity of wave in feet per second.
T = Time of wave in seconds.
D = Depth of water in feet.
H = Height of wave in feet.
L = Length of wave in feet.

$$\left.\begin{aligned} T &= \cdot 55 \sqrt{L} \\ V &= 1 \cdot 818 \sqrt{L} \end{aligned}\right\} \text{ when L is less than D.}$$

$$V = \sqrt{32 \cdot 17\, D} \text{ when L exceeds 1000 D.}$$

$$V = \sqrt{32 \cdot 17\, D \left(1 + 3\frac{H}{D}\right)} \text{ when the height}$$

of the wave bears a sensible proportion to the depth.

WAVES—*continued.*

Mr. Scott Russell divides waves into two classes:—

Waves of translation, or of the 1st order.
" oscillation, " 2nd "

WAVES OF THE 1ST ORDER.

1. Velocity not affected by the intensity of the generating impulse.

2. Motion of the particles always forward in the same direction as the wave, and the same at the bottom as at the surface.

3. Motion of the particles most intense in a vertical line below the crest; the particles at rest in the trough.

4. Character of the wave, a prolate cycloid in long waves, approaching a true cycloid as the height of the wave approaches the proportion of $\frac{1}{3}$rd of its length. When the height is more than $\frac{1}{3}$rd of the length, the wave breaks.

WAVES OF THE 2ND ORDER.

1. Ordinary sea waves are waves of the 2nd order, but become waves of the 1st order as they enter shallow water.

2. Character cycloidal.

3. Motion of water alternately flowing to and from a point. Towards the top of the wave the movement of particles is in the direction of the wave; but in the trough the movement is in the opposite direction.

WAVES—*continued.*

4. Motion greatest at crest and at lowest portion of trough; no motion at half height of wave.

5. Power of destruction directly proportional to height of wave, and greatest when crest breaks.

6. A wave of 10 feet high, 32 feet long, would only agitate the water 6 inches at 10 feet below the surface; a wave 10 feet high and 100 feet long would only disturb the water 18 inches at the same depth.

7. At a depth = the length of the wave, the motion is diminished to $\frac{1}{534}$ of that at the surface.

8. A wave 30 feet high may exert a pressure of nearly 1 ton per square foot of surface.

9. In exposed position, and in deep water, $1\frac{2}{3}$ ton may be exerted by waves striking suddenly on a vertical surface.

10. The height of a wave does not equal the depth of water, but it nearly approaches that limit.

VELOCITY OF FREE WAVES IN FEET PER SECOND, WHEN THE LENGTH OF WAVE EXCEEDS 1000 DEPTH.

Depth of Water *in feet.*

Depth ..	1	2	3	4	5	8	10	20	30
Velocity ..	5·7	8	9·8	11	12·6	16	18	25	31
Depth ..	40	60	80	100	200	400	600	800	1000
Velocity ..	36	45	51	57	80	113	139	160	179

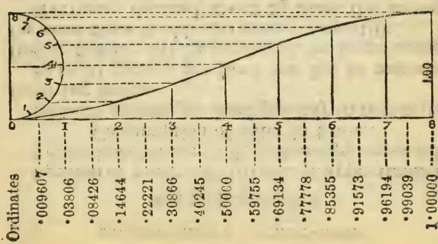
Velocity of Waves in Feet per Second, when Length does not exceed the Depth of Water.

Length of Wave *in feet.*

Length ..	2	4	6	8	10	20	30	40	50
Velocity .	2·57	3·63	4·46	5·14	5·73	8·13	9·95	11·50	12·85
Length ..	100	200	300	500	1000	2000	3000	4000	10,000
Velocity .	18·2	25·7	31·5	40·6	57·3	81·3	99·6	115	182

FORM OF WAVES.

When waves are very long compared with their height, their form may be approximately determined by dividing the length of the wave, as measured from crest to crest, into a given number of equal parts and dividing the circumference of a circle (whose diameter = the height of the wave) into the same number of equal parts as shown in the diagram—the outline of the wave passes nearly through the intersection of horizontal and vertical lines projected from such point. The lengths of ordinates are given below for divisions of a wave into 16 and 32 parts.



WATER-WORKS.

1 gallon of water = $0 \cdot 16$ cubic ft. approximately.
1 cube foot of water = $6\frac{1}{4}$ gallons approximately.

Consumption of water in towns.

16 to 20 gallons per head per day in non-manufacturing towns.

20 to 30 gallons per head per day in manufacturing towns: the main should be large enough for more than double the average quantity.

Maximum demand about $2\frac{1}{2}$ times the average demand.

Impounding reservoirs should contain above 120 days' supply in the rainy districts, and 200 days' supply in the less rainy districts of England.

Service reservoirs should contain 3 days' supply.

On the average about $\frac{6}{10}$ths of the rainfall is available for storage.

Loss from overflow of storm-water about 10 per cent.

Evaporation 50 per cent. less on flat country than on an undulating rocky country.

Infiltration in England, in Winter	..	33 per cent.
„ „ Spring	..	35 „
„ „ Summer	..	2 „
„ „ Autumn	..	48 „
Average of the Year	..	42 „

RAINFALL.

Greatest rainfall in England in 24 hours, about 3 inches.

Annual rainfall in England from 20 to 70 inches.

Mean	42	„
In India, in the plains	50 to 70	„
„ in the hills	130 to 190	„
Cape	23	„
Tasmania	35	„
Greatest evaporation in 24 hours in India about	·56	„
Mean daily evaporation in India ..	·20	„
„ „ England ..	·08	„

Water-Works—*continued.*

Filters for Water-works.

1 square yard of filter for each 700 gallons in 24 hours; formed of 2 ft. 6 in. of fine sand.
" 6 in. of common sand.
" 6 in. of shells.
" 2 ft. 6 in. of gravel.
Perforated pipes laid in the lowest stratum.

Hawksley's Rule for the Storage of Water.

$D =$ Number of days' supply to be stored $= \frac{1000}{\sqrt{F}}$.

$F =$ Mean annual rainfall in inches of three consecutive dry years, say $\frac{5}{6}$ of the average annual rainfall.

Storage capacity in England varies from 25,000 to 50,000 cubic feet per acre of catchment area.

Coating for Pipes.

The pipes are lowered into a bath containing a composition of gas-tar, Burgundy pitch, oil, and resin, heated to 400° Fahr., and remain until they attain the heat of the bath, they are then placed in an upright position to allow the superfluous coating to drain off.

Pumping Engines.

Compound reciprocating engines, with double-acting pumps, are chiefly used for water-works.

They give a duty of from 95 to 100 (duty reduced to 112 lbs. of coal), compared with a duty of from 50 to 70 for Cornish engines.

Large air-vessels are now very generally used in preference to stand-pipes, but arrangements should be made for supplying the air-vessel with air.

Mains or Pipes.

The velocity of water in the pipes should not exceed 3 feet per second.

Reflux flaps should be placed at intervals in long pumping mains, to prevent back pressure on the engine. Relief valves should also be used to prevent excessive pressure. Pipes should not rise more than 22 feet above the mean hydraulic gradient, and air-valves should be placed at high places in the main where air is likely to accumulate.

COMPOUND PUMPING ENGINES WITH DOUBLE-ACTING PUMPS.

	Lambeth.	Vienna.	Lawrence.	Hanover.	Chis-wick.
Character	Rotative	Rotative	Rotative	Rotative	Direct
Revolutions per min.	14	20	16¼	24	—
Diam. of large cyl., ins.	46	22¾	38	36⅝	20
" small " "	28	11	18	20⅞	10
Area of large cyl., "	1662	406·4	1134	1053·5	314·1
" small " "	616	95	254·4	342·2	78·5
Stroke of large " "	96	58⅞	96	53	36
" small " "	66⅜	58⅞	96	53	36
Capacity, large " "	159452	23927	108864	55836	11308
Ratio of clearance and passages ..	·048	—	·116	—	—
Capacity, small cyl., ins.	40870	5593	24442	18136	2826
Ratio of clearance, &c.	·027	—	·0243	—	—
Relative capacity of cylinders	1 to 3·9	1 to 4·3	1 to 4·45	1 to 3·08	1 to 4
Relative area of cylrs.	1 to 2·7	1 to 4·3	1 to 4·45	1 to 3·08	1 to 4
Stroke of pump, ins.	83⅜	29½	96	29½	36
Diameter of pump barrel, ins... ..	23⅜	21⅛	26⅛	19¾	21
Diameter of pump plunger	16½	—	18	—	15
Initial pressure, lbs. per sq. in... ..	35*	67½	100	80	—
Mean pressure, small cylinder	24	—	—	—	—
Mean pressure, large cylinder	— 6½	—	—	—	—
Fuel consumption, lbs. I.H.P. per hour	1·7	—	1·69	—	—
Duty of 1 cwt. coal (millions) † ..	97	—	107	—	—
Percentage lost by friction	20	—	—	—	—
Head of water, feet ..	210	26¼	170	133	—
Diam. of main, ins. ..	30	23⅝	24	19¾	—
Velocity of water in main, ft. per sec.	—	1½	—	—	—
Indicated HP.	—	24½	195½	—	—
Capacity, air vessel, c. f.	—	—	—	166	—

* The Lambeth engines are sometimes used with 40 lbs. initial pressure, cutti off at 20 per cent. of the small cylinder.

† The duty of Cornish engines varies from 51 to 68 millions of foot-lbs. for 1 c of coal.

PUMPING ENGINES.

G = Number of gallons to be raised in 24 hours.
F = Number of cube feet raised in 24 hours.
h = Height in feet to which the water is to be raised.

HP = Actual horse-power required

$$HP = \frac{G \times h}{4752000} \text{ or } \frac{F \times h}{762088}.$$

20 per cent. must be added to overcome a friction, &c., and 50 or 60 per cent. more is usually allowed for contingencies, making a total of 70 or 80 per cent. additional power.

TO FIND THE DIAMETER OF A SINGLE-ACTING PUMP.

L = Length of stroke in feet.
G = Number of galls. to be delivered per minute.
F = Number of cub. ft. to be delivered per minute.
N = Number of strokes per minute.
D = Diameter of pump in inches

$F = \cdot 00545\ D^2 L N.$

$G = \cdot 034\ D^2 L N.$

$$D = \sqrt{\frac{G}{\cdot 034\ L N}}$$

$$D = \sqrt{\frac{F}{\cdot 00545\ L N}}$$

Note.—These formulæ give the net diameter of the pump-plunger; it is usual to increase the area of the plunger $\frac{1}{4}$th, to allow for leakage, &c.

USEFUL NUMBERS FOR PUMPS.

D = Diameter of pump in inches.
S = Stroke of pump in inches.
$D.^2 S \times \cdot 7854$ = cubic inches.
$D.^2 S \times \cdot 002833$ = gallons.
$D.^2 S \times \cdot 0004545$ = cubic feet.
$D.^2 S \times \cdot 02833$ = lbs. fresh water.

Cast Iron Water Pipes.

To bear a pressure of 200 feet of water or proof of 400 feet.

Bore in Inches.	Thickness of Metal.	Depth of Socket.	Thickness of Socket.	Space for Packing.	Weight of 9-feet Length.*			Weight of Lead Joint.
	inches.	inches.	inches.	inches.	cwt.	qrs.	lbs.	lbs.
3	$\frac{5}{16}$	3	$\frac{5}{8}$	$\frac{1}{4}$	0	3	24	2·4
4	$\frac{5}{16}$	3	$\frac{5}{8}$	$\frac{1}{4}$	1	1	14	3·6
5	$\frac{3}{8}$	$3\frac{1}{4}$	$\frac{5}{8}$	$\frac{3}{8}$	1	2	16	6·0
6	$\frac{3}{8}$	$3\frac{1}{4}$	$\frac{5}{8}$	$\frac{3}{8}$	2	0	0	8·2
7	$\frac{3}{8}$	$3\frac{1}{4}$	$\frac{5}{8}$	$\frac{3}{8}$	2	1	4	8·7
8	$\frac{7}{16}$	$3\frac{1}{4}$	$\frac{5}{8}$	$\frac{3}{8}$	3	0	4	9·9
9	$\frac{7}{16}$	4	$\frac{3}{4}$	$\frac{3}{8}$	3	1	19	13·9
10	$\frac{1}{2}$	4	$\frac{3}{4}$	$\frac{3}{8}$	4	1	16	14·9
11	$\frac{1}{2}$	4	$\frac{3}{4}$	$\frac{3}{8}$	4	2	22	15·9
12	$\frac{9}{16}$	4	$\frac{7}{8}$	$\frac{3}{8}$	5	2	24	17·2
14	$\frac{5}{8}$	4	$\frac{7}{8}$	$\frac{3}{8}$	7	2	4	20·8

* The 9-feet length is taken from the end of one pipe to the end of the next when laid.

Cast-iron Pipes—Pressure in.

Let H = Head of water in feet.
P = Pressure of water in lbs. per square inch.
d = Internal diameter of pipe in inches.
t = Thickness of metal in inches.

$$P = 0·433\,H.$$

$$t = 0·000054\,H\,d + x.$$

$$\text{or } t = ·000125\,P.d + x.$$

x = ·37 ins. for pipes less than 12 ins. diam.
= ·5 for pipes from 12 to 30 inches.
= ·6 for pipes from 30 to 50 ins. diameter.

Rule for finding the Weight of Cast-iron Pipes.

D = Diameter outside in inches.
d = Diameter inside, or bore in inches.
W = Weight of 1 yard of pipe in lbs.

$$W = 7·35\,(D^2 - d^2).$$

The weight of two flanges = about 1 foot of pipe.

Dimensions of Pipes used at the Glasgow W ter-works.
(J. F. Bateman, Engineer.)

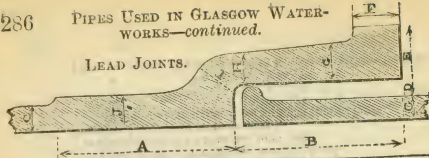
Bore of Pipe.	Length of each Pipe.	Thickness of Metal.	Weight				Working Head.	
			Per Pipe.			Per Foot Run.	Feet of Water.	Lbs. per sq. inch.
ins.	feet.	inch.	cwt.	qrs.	lbs.	cwt.		
33	12	1	39	1	25	3·29	210	91
30	12	$1\frac{1}{4}$	44	0	3	3·67	300	130
30	12	1	35	3	5	2·98	230	100
24	12	1	28	1	23	2·37	300	130
20	9	$\frac{7}{8}$	16	0	4	1·78	270	118
20	9	$\frac{3}{4}$	13	3	25	1·55	240	104
18	9	$\frac{13}{16}$	13	1	12	1·48	300	130
18	9	$\frac{3}{4}$	12	1	19	1·38	260	113
18	9	$\frac{11}{16}$	11	1	27	1·27	230	100
16	9	$\frac{3}{4}$	10	3	27	1·22	300	130
16	9	$\frac{11}{16}$	10	0	18	1·13	250	108
16	9	$\frac{5}{8}$	9	1	9	1·04	200	86
15	9	$\frac{11}{16}$	9	2	3	1·06	270	118
15	9	$\frac{9}{16}$	7	3	25	·88	180	78
14	9	$\frac{11}{16}$	8	3	23	·99	290	125
14	9	$\frac{5}{8}$	8	0	25	·91	250	108
14	9	$\frac{9}{16}$	7	2	0	·83	200	86
12	9	$\frac{5}{8}$	6	3	13	·76	290	125
12	9	$\frac{9}{16}$	6	0	26	·693	240	104
10	9	$\frac{9}{16}$	5	0	16	·571	300	130
9	9	$\frac{9}{16}$	4	2	24	·524	300	130
8	9	$\frac{1}{2}$	3	2	23	·412	300	130
7	9	$\frac{1}{2}$	3	1	1	·362	300	130
6	9	$\frac{7}{16}$	2	1	27	·277	300	130
5	9	$\frac{13}{32}$	1	3	24	·218	300	130
4	9	$\frac{3}{8}$	1	1	20	·158	300	130
3	9	$\frac{3}{8}$	1	0	10	·121	300	130
2	6	$\frac{3}{8}$	0	2	4	·089	300	130

Note.—The length does not include the length of the socket.
The weight includes the weight of the socket
The proof strain is double the working head.
For dimensions of sockets, see next page.
Permitted deviation from weight:—

2 per cent. in pipes from 20 to 33 inches bore.
$2\frac{1}{2}$ " " 13 to 18 "
3 " " 8 to 12 "
4 " " 2 to 7 "

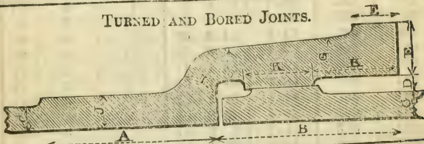
Pipes exceeding 18 inches bore to be cast socket downwards,

LEAD JOINTS.



Bore. Inches.	A.	B.	C.	D.	E.	F.	G.	H.	I.	J.
2	3	3	3/8	1/4	7/8	3/4	11/16	5/8	3/4	1/2
3	3	3	3/8	1/4	7/8	3/4	11/16	5/8	3/4	1/2
4	3	3	3/8	1/4	7/8	3/4	11/16	5/8	3/4	1/2
5	3½	3½	7/16	3/8	1	7/8	13/16	11/16	7/8	5/8
6	3½	3½	7/16	3/8	1	7/8	13/16	11/16	7/8	5/8
7	3½	3½	1/2	3/8	1	7/8	13/16	11/16	7/8	5/8
8	4	4	1/2	3/8	1⅛	1	13/16	11/16	7/8	5/8
9	4	4	9/16	3/8	1⅛	1	13/16	11/16	7/8	5/8
12	4	4	5/8	3/8	1¼	1	15/16	13/16	1⅛	3/4
15	4½	4½	11/16	3/8	1⅜	1⅛	1 1/16	15/16	1¼	7/8
18	4½	4½	13/16	3/8	1½	1¼	1⅛	1	1¼	1
20	4½	4½	7/8	3/8	1⅝	1⅜	1¼	1⅛	1¼	1⅛
24	5	5	1	3/8	1¾	1½	1⅜	1¼	1½	1⅛
33	5½	5	1	3/8	2	1¾	1½	1⅜	1⅝	1 5/16

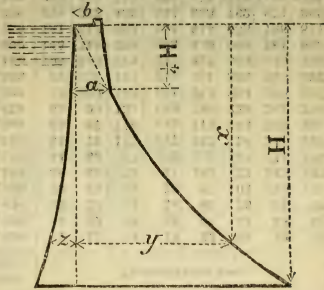
TURNED AND BORED JOINTS.



Bore. Inches.	A.	B.	C.	D.	E.	F.	G.	H.	I.	J.	K.
2	3	3	3/8	1/4	7/8	3/4	11/16	5/8	3/4	1/2	1¼
3	3	3	3/8	1/4	7/8	3/4	11/16	5/8	3/4	1/2	1¼
4	3	3	3/8	1/4	7/8	3/4	11/16	5/8	3/4	1/2	1¼
5	3½	3½	7/16	3/8	1	7/8	13/16	11/16	7/8	5/8	1⅜
6	3½	3½	7/16	3/8	1	7/8	13/16	11/16	7/8	5/8	1⅜
7	3½	3½	1/2	3/8	1	7/8	13/16	11/16	7/8	5/8	1⅜
8	4	4	1/2	3/8	1⅛	1	13/16	11/16	7/8	5/8	1⅝
9	4	4	9/16	3/8	1⅛	1	13/16	11/16	7/8	5/8	1⅝
12	4½	4½	5/8	3/8	1¼	1	15/16	13/16	1	3/4	1¾

Taper of bored portion $\frac{1}{32}$ inch per inch of length.

High Dams in Masonry for Reservoirs.



H = Height of dam in feet.

x = Any depth below the surface of water in feet.

y = Offset from vertical line to outer face of dam at any depth x in feet.

z = Ditto, ditto to inner face in feet.

b = Width of dam at top in feet.

a = Width of dam at $\frac{1}{4}$ H from top in feet.

P = Limit of pressure allowed on the masonry in tons per square foot.

= 9 tons in the dam of La Terrasse.

$$y = \sqrt{\frac{\cdot 05\, x^3}{P + (\cdot 03\, x)}}\,; \quad z = \left(\frac{\cdot 09\, x}{P}\right)^4;$$

$b = 0 \cdot 4\, a$;

If y as given by the formula be less than $0 \cdot 6\, x$, it must be increased to $0 \cdot 6\, x$.

Low Masonry Dams.

Width at bottom = height × 0·7.
Width at middle = height × 0·5.
Width at top .. = height × 0·3.

Earthen Reservoir Dams.

Width at top in high dams from 7 to 20 feet.
Width at top in low dams .. = height.
Breast slopes .. .. .. = 3 to 1.
Back slopes .. .. = 2 to 1.
Height above surface of water not less than 3 feet 6 inches.

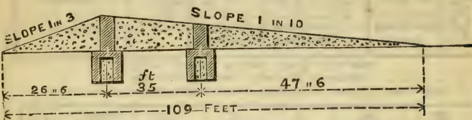
Table of Rainfall, showing the Quantity of Water Due to a given Rainfall over a given Area.

Rainfall in Inches.	Area of Catchment in Acres.									One Square Mile.
	1	2	3	4	5	6	7	8	9	
	Cube feet.	Thousand cube feet.								Million cube ft.
1	3,630	7	11	14	18	22	25	29	33	2⅓
2	7,260	14	22	29	36	44	51	58	65	4½
3	10,890	22	33	44	54	65	76	87	98	7
4	14,520	29	44	58	73	87	102	116	131	9¼
5	18,150	36	54	73	91	109	127	145	163	11½
6	21,780	44	65	87	109	131	152	174	196	14
7	25,410	51	76	102	127	152	178	203	229	16¼
8	29,040	58	87	116	145	174	203	232	261	18½
9	32,670	65	98	131	163	196	229	261	294	21
10	36,300	73	109	145	181	218	254	290	327	23¼
12	43,560	87	131	174	218	261	305	348	392	27¾
15	54,450	109	163	218	272	327	381	436	490	34¾
20	72,600	145	218	290	363	436	508	581	653	46½
25	90,750	181	272	363	454	544	635	726	817	58
30	108,900	218	327	436	544	653	762	871	980	69¾
40	145,200	290	436	581	726	871	1016	1162	1307	93
50	181,500	363	544	726	907	1089	1270	1452	1633	116¼
60	217,800	436	653	871	1089	1307	1525	1742	1960	139½

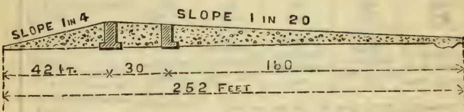
Weirs on Indian Rivers.

DIAGRAMS SHOWING SECTIONS OF WEIRS ON THE SOANE AND JUMNA RIVERS.

SOANE WEIR.



JUMNA WEIR (AGRA CANAL)



The Soane Weir is on a better bed than the Jumna Weir, which is on a very fine sand mixed with mica and very easily eroded.

Both weirs are formed of large blocks of loose stone with nucleus walls which run through their entire length.

The walls of the Soane Weir are 5 feet thick, supported on rows of piles sunk 10 feet deep into the bed of the river.

The walls of the Jumna Weir are 4 feet thick, built on the river bed.

The Soane Weir is 8 feet high at its crest.

The Jumna Weir is 10 feet high at its crest.

Drainage of Land.

Soil.	Depth of Pipes.	Distance of Pipes apart.
	ft. in.	feet.
Stiff clay	2 6	15
Friable ditto	2 0	18
Soft ditto	2 9	21
Loam with clay	3 2	21
Loam with gravel	3 3	27
Light loam	3 6	33
Sandy ditto	3 9	40
Light sand with gravel	4 0	50
Coarse gravelly sand	4 6	60

Table of the Power required to Raise Water from Deep Wells. (J. T. Hurst.)

Diameter of Pump Barrel.	Description of Pump.	Quantity of Water Raised per hour.	Maximum Depth from which this Quantity can be Raised by each Unit of Power.			
			One Man turning a Crank.	One Donkey working a Gin.	One Horse working a Gin.	One Horse-power Steam-Engine.
inches.		gallons.	feet.	feet.	feet.	feet.
2	Double-	225	80	160	560	880
$2\frac{1}{2}$	action	360	50	100	350	550
3	lift and	520	35	70	245	385
$3\frac{1}{2}$	force	700	25	50	175	275
4	pump.	900	20	40	140	220

Comparative Performance of Methods used in India for Raising Water. (Roorkee Treatise.)

Height raised = 40 feet. Day = 8 hours.

Method.	Stages.	Usual Effect per cent.	Discharge per hour.		Discharge per diem.		Ratio of Discharge.	Power Employed.		Relative Cost of Raising Water.
			Cube feet.	Gallons.	Cube feet.	Gallons.		Men.	Bullocks.	
Paecottah	2·5	90	29·07	181·4	232	1451	1	2	—	2·7
Baling *	8	75	37·5	236·2	300	1875	1·29	4	—	4·2
Single môt ..	1	70	149·5	924	1196	7392	5·1	1	2	1·3
Double môt ..	1	65	165·8	1045	1326	8360	5·7	1	2	1·2
Single Persian Wheel ..	1	55	69·3	429	554	3432	2·4	1	2	2·8
Double ditto ..	1	60	198	1242	1704	9936	6·8	1	2	1

* Calculated on $\frac{1}{8}$th of the quantity raised 5 feet. The ratio of discharge is taking the Paecottah as 1. The relative cost is taking the Double Persian Wheel as 1. Cost and wear and tear of machinery is not included.

Irrigation in India.

Proportion of Rainfall running off into Outfalls.

(From observations at Nagpur by A. Binnie.)

Monsoon rainfall, inches ..	6·77	19·47	29·79	31·29	39·28	43·65	53·72
Proportion running off ..	·047	·16	·268	·31	·40	·40	·40

In Mysore the proportion running off is assumed at ·25.

Loss of Water in Tanks in Rajputana (Culcheth).

Days.	By Evaporation.	By Absorption, &c.	Total.
	feet.	feet.	feet.
October to March, 182	2·32	·75	3 07
April to June, 91	2·24	1·34	3·58
July to September, 92	1·59	1·53	3·12
Total 365	6 15	3·62	9·77
Average per day .. .. feet	·017	·01	·027
" " .. inches	·202	·119	·321

In the Deccan the loss by evaporation, absorption, leakage, &c., from October to March was found to be 3·51 feet in 182 days = ·0193 feet per day. From April to May 2·03 feet in 61 days = ·0333 feet per day.

Loss by Evaporation only, in Feet.

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	Total 8 Mon.
Rajputana	·49	·35	·29	·29	·35	·55	·73	·81	3·86
Bombay	·65	·49	·37	·44	·34	·44	·69	·99	4·41
Nagpur	·50	·42	·37	·33	·32	·48	·76	·59	3·77

Or an average of ·016 feet = ·198 per day.

From observations Mr. Binnie deduces the following rule:— If the average annual rainfall = 1·00, the minimum will equal about ·65; maximum about 1·40; and the average of three consecutive dry years ·83.

Duty of Water in Irrigation.

A constant flow of 1 cubic foot per second will irrigate the following acreage. Tanjore, rice 44 acres; Mysore, rice in ordinary soil, 30; in black cotton soil, 35; Sind, rice, 40; Bombay (Deccan), rice, 40; sugar-cane, 100; ordinary winter crops, 150; 6 and 8 month crops, 150; Monsoon crops (usually grown without irrigation) 200.

IRRIGATION IN INDIA—*continued.*

In moist districts the following allowance is made for rice—

Per day of 24 hours	= $\frac{1}{3}$ inch of water.	
" "	= 1210 cubic feet per acre.	
Or per crop	= 87,000 cube feet	"

In some parts it is usual to allow for waste, and so to assume—

Per day of 24 hours ..	= $\frac{1}{2}$ inch of water.	
" " ..	= 1815 cubic feet.	
Or per crop	= 130,000 "	"
Common grain per day	= ·12 inch.	
" "	= 436 cube feet.	

In Central India, to allow for evaporation, the storage room is from 200,000 to 250,000 cubic feet per acre.

The discharge of channels is frequently calculated at ·02 cubic foot per second per acre; this is equivalent to nearly $\frac{1}{2}$ inch per day. In some cases ·03 is allowed.

A proportion for channels sometimes adopted is D = Depth in feet, B = Breadth at bottom in feet.

A = Area in square feet.

$D = \sqrt{\frac{A}{3}}$. This proportion gives

B = 2 D, with slopes of 1 to 1.

= $1\frac{1}{2}$ D, with slopes of $1\frac{1}{2}$ to 1.

And a mean hydraulic depth of

·62, with slopes of 1 to 1.

·59, " " $1\frac{1}{2}$ to 1.

The velocity in feet per second should not be less than 2 feet per second, nor more than $3\frac{3}{4}$ feet per second, unless the material through which the channel is excavated be very hard. Large channels with turbid water require the higher velocity to prevent silting.

IRRIGATION—*continued.*

TABLE SHOWING THE ACREAGE IRRIGATED BY DIFFERENT SIZES OF CHANNEL.

Number of Acres Irrigated.	Area of Channel in Sq. Ft., with Velocities in Feet per Second = 2	2½	3	3½	4	5	6
	sq. ft.	sq. ft.	sq. ft.	sq. ft.	sq. ft.	sq. ft.	sq. ft.
100	1	·8	·66	·57	·5	·4	·3
200	2	1·6	1·3	1·1	1	·8	·7
300	3	2·4	2	1·7	1·5	1·2	1
400	4	3·2	2·6	2·3	2	1·6	1·3
500	5	4·0	3·3	2·8	2·5	2	1·7
600	6	4·8	4·0	3·4	3	2·4	2
700	7	5·6	4·7	4	3·5	2·8	2·3
800	8	6·4	5·3	4·6	4	3·2	2·7
1000	10	8	6·7	5·7	5	4	3·3
2000	20	16	13·3	11	10	8	6·7
3000	30	24	20	17	15	12	10
4000	40	32	26·7	23	20	16	13
5000	50	40	33	28	25	20	17
1 Sq. Mile.	6·4	5·12	4·26	3·66	3·2	2·56	2·13

TABLE SHOWING, APPROXIMATELY, DIMENSIONS BEST ADAPTED FOR IRRIGATION CHANNELS IN NORTHERN INDIA.

('Min. Inst. Civ. Eng.,' vol. xxvii., p. 479, Login.)

Discharge per Second.	Calculated Sections. Mean Velocity per Second.	Hydraulic Mean Depth.	Breadth at Bottom.	Depth of Water.	Slope of Surface per Mile.	Proposed Sections. Breadth at Bottom.	Depth of Water.	Slope of Surface per Mile.	Side Slopes.
cub. ft.	feet.	feet.	feet.	feet.	inches.	feet.	feet.	inches.	
50	2	2	2½	4	15	2	4½	16½	1 to 1
100	2¼	2½	4½	4¾	14½	4	5¼	16	1 „ 1
250	2½	3⅓	15	5	13½	13½	5½	14⅚	1 „ 1
500	2¾	4¼	27½	5½	13	25	6	14⅓	1 „ 1
1000	3	5	50	6	13	45	6⅔	14⅓	1 „ 1
2000	3¼	6	77½	7	13	70	7¾	14⅓	1½ „ 1
3000	3½	7	95	8	12¾	85	8⅘	14	1½ „ 1
4000	3½	7½	121½	8½	12¾	110	9⅓	14	1½ „ 1
5000	3⅔	7⅔	147½	8½	12½	130	9⅓	13¾	1½ „ 1
6000	3¾	8	170	8¾	12½	150	9⅔	13¾	1½ „ 1

IRRIGATION—*continued.*

IRON SLUICES.

H = Head of water in feet.
A = Area of sluice in inches.
v = Theoretical velocity due to head of water in feet per minute $= 482 \sqrt{H}$. For Table of value of v, see 'Theoretical velocity of water."
Q = Quantity of acres irrigated.
$= \cdot 0033\, A\, v$.

This is calculated on the assumption that the coefficient of discharge = ·6, and that ¼ an inch of water including waste is supplied in 24 hours, and that the sluice-pipe is circular.

Head of Water.	Diameter of Sluice-pipe in inches.							
	6	8	9	12	16	18	24	13 55 *
feet.	acres.	acres.	acres.	acres.	acres.	acres.	acres.	acres.
2	63	113	143	254	452	572	1016	323
4	90	160	202	360	640	809	1439	458
6	110	195	248	440	783	991	1761	561
8	127	226	286	509	904	1156	2035	648
10	142	252	320	569	1011	1280	2275	723
15	174	309	391	696	1238	1567	2785	887
20	201	357	452	804	1430	1809	3222	1024
30	246	437	554	985	1751	2217	3941	1254
40	284	505	640	1037	2022	2558	4550	1448
50	318	565	715	1272	2261	2861	5088	1619

* Or one square foot. 13·55 gives an area of one square foot. Area in square feet $\times \cdot 475\, v = Q$.

PRESSURE ON SLUICES.

Let D = Mean depth of sluice below surface in feet.
A = Area of sluice in square feet.
P = Pressure on sluice in lbs.
K = Coefficient of friction.
X = Power required to work the sluice in lbs.
$P = A \times 62 \cdot 4\, D$.
$X = K \times P$.
$K = 0 \cdot 68$ when the sluice is of wood.
$K = 0 \cdot 31$ " " metal.

For other coefficients of friction, see "Friction."

Docks.

Ordinary docks vary from 3 to 30 acres, with from 400 to 2000 lineal yards frontage.

Locks: 40 to 80 feet width.
25 „ 30 „ depth on sill.
400 „ 600 „ length.

Graving docks: from 45 to 100 ft. width.
30 „ 35 „ depth on sill.
500 „ 700 „ long in blocks.

Clark's hydraulic dock:
Pontoons from 150 to 320 feet long × 59 feet broad.

Floating docks (graving), Rennie's:—
350 feet long; width inside, 76 feet; width outside = 105 feet.

Depth over keel-block when sunk = 28 feet.

8 pumps: 33-inch stroke, 26 inches diameter.

2 engines: high pressure, 18-inch cylinder, 2-feet stroke.

BERMUDA FLOATING DOCK.

	Outside.	Inside Dimensions
Length	381 feet ..	380 feet.
Breadth	124 „ ..	84 „
Depth	72 „ ..	52 „

Pressure on Lock Gates, &c.

D = Depth of water on gate in feet.
P = Pressure on gate.
A = Area of surface exposed to the water in square feet.

$$P \text{ in lbs.} = A \times 31{\cdot}2\,D.$$
$$P \text{ in cwts.} = A \times {\cdot}278\,D.$$

Best angle for lock gates = about 136°, or a ratio of rise to span = 1 to 5.

For circular gates the best ratio of rise to span = 1 to 3.

Iron Piles for Retaining Walls.

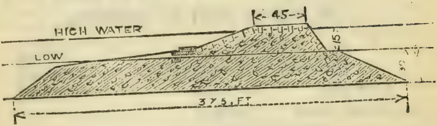
Main piles, 7 feet apart; 1 foot 6 inches wide; metal, 2 inches thick, with 2 ribs 8 inches deep.

Plates, 7 × 5 feet, × 1 inch; with diagonal feather, 6 × 1.

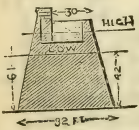
Diameter of tie-rods, 2 inches.

Breakwaters.

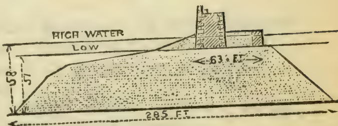
PLYMOUTH.



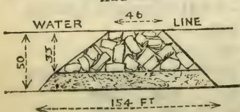
DOVER.



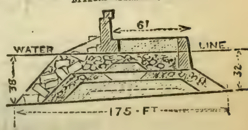
PORTLAND.



ALGIERS.



MARSEILLES.



PLYMOUTH BREAKWATER.

Depth of water, high tide, 46 ft. 6 in.

" low " 30 ft.

BREAKWATERS—*continued.*

PLYMOUTH BREAKWATER—*continued.*

Outer slopes—$1\frac{3}{4}$ to 1 from bottom to 7 ft. 6 in. below low-water line.
4 to 1 to low-water line.
16 „ 1 to 4 ft. 6 in. above low-water line.
5 to 1 to high water.

Inner slope—$1\frac{1}{2}$ to 1 above low-water line.
2 „ 1 below „ „

Body of breakwater cased with large squared stones cramped together.

PORTLAND.

Depth of water, 58 feet, high.
„ „ 51 „ low.
Outer slopes—1 to 1 from bottom to 20 ft. below low water.
2 to 1 to 12 ft. below low water.
6 „ 1 to low-water line.
4 „ 1 to high „
Inner slope—$1\frac{1}{4}$ to 1.
Body of breakwater, rubble, with crest wall of ashlar.

DOVER.

Depth of water, 61 feet, high-water line.
„ „ 42 „ low „
Body of breakwater, concrete blocks faced with granite; batter 3 inches to the foot, stepped up in each course.

BREAKWATERS—*continued.*

MARSEILLES.

Depth of water, 33 feet.

Outer casing of beton, $25\frac{1}{2}$ tons each.

Average thickness of casing from 14 to 20 feet.

Slope 1 to 1 from bottom to water line.

$2\frac{1}{2}$ to 1 above water line. All other slopes $\frac{1}{3}$ to 1.

Inner casing of first-class rubble (of stones 2 to 5 tons weight), about 12 feet thick.

Hearting, second-class rubble (of stones $\frac{1}{2}$ to 2 tons weight), about 6 feet thick.

Nucleus of quarry rubbish.

ALGIERS.

Depth of water, 50 feet.

Rubble base carried up to 33 feet from surface of water; the remainder composed of large beton blocks, $25\frac{1}{2}$ tons each.

Slopes of rubble base, 1 to 1.

Outer slope of beton blocks, $1\frac{1}{4}$ to 1.

Inner ,, ,, 1 ,, 1.

PORT SAID (Suez Canal).

Concrete blocks, 10 cubic mètres each, composed of 1 of hydraulic lime to 13 of sand, mixed with sea water; it remains 4 days in the mould and dries for 4 months before being put in position. In some instances the composition of beton blocks is $\frac{1}{3}$ lime or cement to $\frac{2}{3}$ sand and broken stone, about the size of a man's fist

BREAKWATERS—*continued.*

Proportion of interstices in breakwaters to the contents of the breakwater as it stands:—

3rd-class rubble or quarry rubbish,		$\frac{1}{6}$	interstices.
2nd " "	$\frac{1}{2}$ to 2 tons,	$\frac{1}{5}$	"
1st " "	2 " 5 "	$\frac{1}{4}$	"
Beton blocks,	15 " 25 "	$\frac{1}{3}$	"

At Cassis, when the water is deep outside, blocks of 15 cubic mètres were found insufficient to resist the action of waves.

Breakwaters with vertical walls or faces of an angle less than 1 to 1, will reflect waves without breaking them. Waves of oscillation have no effect on small stones at 22 feet below the surface,* or on stones from $1\frac{1}{2}$ to 2 feet, 12 feet below the surface.

A roller 20 feet high will exert a force of about 1 ton per square foot.

Greatest force observed at Skerryvore, 3 tons per square foot.

Ditto, ditto, Bell Rock, $1\frac{1}{2}$ ditto.

The action of waves is most destructive at low-water line.

Waves of the 1st order are nearly as powerful at a great depth as at the surface.

At Madras harbour laterite rubble, 150 lbs. per cubic foot, in blocks varying from 5 lbs. to 2 cwt., were removed at depths exceeding 40 feet by cyclonic ground swell; at Wick harbour a mass of 1300 tons was bodily removed by the waves without breaking up.

* 'Min. Inst. Civ. Eng.,' vol. xviii.

Standards of Electrical Resistance.

(Committee of British Association, 1863.)

FUNDAMENTAL UNITS.

Length $= L$. Time $= T$. Mass $= M$.

DERIVED MECHANICAL UNITS.

Work $= W = \dfrac{L^2 M}{T^2}$. Force $= F = \dfrac{L M}{T^2}$.

Velocity $= V = \dfrac{L}{T}$.

DERIVED MAGNETICAL UNITS.

Strength of the pole of a magnet .. $m = L^{\frac{3}{2}} T^{-1} M^{\frac{1}{2}}$.
Moment of a magnet .. .. .. $ml = L^{\frac{5}{2}} T^{-1} M^{\frac{1}{2}}$.
Intensity of magnetic field .. .. $H = L^{-\frac{1}{2}} T^{-1} M^{\frac{1}{2}}$.

ELECTROMAGNETIC SYSTEM OF UNITS.

Quantity of electricity .. .. .. $Q = L^{\frac{1}{2}} \times M^{\frac{1}{2}}$.
Strength of electric current .. .. $C = L^{\frac{1}{2}} T^{-1} M^{\frac{1}{2}}$.
Electromotive force .. .. .. $E = L^{\frac{3}{2}} T^{-2} M^{\frac{1}{2}}$.
Resistance of conductor.. .. .. $R = L T^{-1}$.

ELECTROSTATIC SYSTEM OF UNITS.

Quantity of electricity .. .. .. $q = L^{\frac{3}{2}} T^{-1} M^{\frac{1}{2}}$.
Strength of electric currents .. .. $c = L^{\frac{3}{2}} T^{-2} M^{\frac{1}{2}}$.
Electromotive force .. .. .. $e = L^{\frac{1}{2}} T^{-1} M^{\frac{1}{2}}$.
Resistance of conductor .. .. .. $r = L^{-1} T$.

Let v be the ratio of the electrostatic to the electromagnetic unit of quantity; then $v = 310{,}740{,}000$ mètres per second approximately, and we have

$$q = v Q; \qquad c = v C; \qquad e = \frac{1}{v} E;$$

$$r = \frac{1}{v^2} R; \qquad s = v^2 S.$$

TABLE FOR THE CONVERSION OF BRITISH (FOOT-GRAIN-SECOND) SYSTEM TO METRICAL (METRE-GRAMME-SECOND) SYSTEM

	No. of Metrical Units contained in a British Unit.	Log.	Log.	No. of British Units contained in a Metrical Unit.
1° for M ..	0·0647989	$\bar{2}$·8115678	1·1884321	15·43235
2° for L, $\frac{v}{1}$, R, $\frac{1}{r}$, and V ..	0·3047945	$\bar{1}$·4840071	0·5159929	3·280899
3° for F (also for foot-grains and mètre-grammes ..	0·0197504	$\bar{2}$·2955749	1·7044250	50·6320
4° for W ..	0·0060198	$\bar{3}$·7795820	2·2204179	166·1185
5° for H and electrochemical equivalents ..	0·461085	$\bar{1}$·6637804	0·3362196	2·16880
6° for Q, C, and e	0·140536	$\bar{1}$·1477874	0·8522125	7·11561
7° for E, m, q, and c	0·0428346	$\bar{2}$·6317949	1·3682051	23·3456
8° for heat ..	0·0359994	$\bar{2}$·5562953	1·4437046	27·7782

BRITISH SYSTEM.

RELATION BETWEEN ABSOLUTE AND OTHER UNITS.

One absolute unit of $\left\{\begin{matrix}\text{force}\\\text{work}\end{matrix}\right.$ $= 0·0310666$ $\left.\begin{matrix}\text{weight of a grain}\\\text{foot-grains}\end{matrix}\right\}$ in London

In London $\left\{\begin{matrix}\text{weight of a grain}\\\text{one foot-grain}\end{matrix}\right.$ $= 32·1889$ absolute units of $\left\{\begin{matrix}\text{force.}\\\text{work.}\end{matrix}\right.$

One absolute unit of $\left\{\begin{matrix}\text{force}\\\text{work}\end{matrix}\right. = \frac{1}{g}\left\{\begin{matrix}\text{unit weight}\\\text{unit weight} \times \text{unit length}\end{matrix}\right\}$ everywhere

g in British system $= 32·088\ (1 + 0·005133\ \sin.^2 \lambda)$, where $\lambda =$ the latitude of the place at which the observation is made.

Heat.—The unit of heat is the quantity required to raise the temperature of one grain of water at its maximum density 1° Fahr.

Absolute mechanical equivalent of unit of heat $= 24861 = 772$ foot-grains at Manchester.

Thermal equivalent of absolute unit of work $= 0 \cdot 000040224$.

Thermal equivalent of foot-grain at Manchester $= 0 \cdot 0012953$.

Electrochemical equivalent of water $= 0 \cdot 02$ nearly.

Metrical System.

Relation between absolute and other units.

$$\text{One absolute unit of} \begin{cases} \text{force} \\ \text{work} \end{cases} = 0 \cdot 0809821 \left.\begin{matrix} \text{weight of a gramme} \\ \text{mètre-gramme} \end{matrix}\right\} \text{at Paris.}$$

$$\text{At Paris} \begin{cases} \text{the weight of a gramme} \\ \text{or mètre-gramme} \end{cases} = 9 \cdot 80868 \text{ absolute unit of} \begin{cases} \text{force.} \\ \text{work.} \end{cases}$$

$$\text{One absolute unit of} \begin{cases} \text{force} \\ \text{work} \end{cases} = \frac{1}{g} \left.\begin{matrix} \text{unit weight} \\ \text{unit weight} \times \text{unit length} \end{matrix}\right\} \text{everywhere.}$$

g in metrical system $= 9 \cdot 78024\ (1 + 0 \cdot 005133 \sin.^2 \lambda)$, where $\lambda =$ the latitude of the place where the experiment is made.

Heat.—The unit of heat is the quantity required to raise one gramme of water at its maximum density 1° Centigrade.

Absolute mechanical equivalent of the unit of heat $= 4157 \cdot 25 = 423 \cdot 542$ mètre-grammes at Manchester.

Thermal equivalent of an absolute unit of work $= 0 \cdot 00024054$.

Thermal equivalent of a mètre-gramme at Manchester $= 0 \cdot 00236154$.

Electrochemical equivalent of water $\simeq 0 \cdot 0092$, **nearly.**

Morse Alphabet.

A · —	H · · · ·	O — — —	V · · · —
B — · · ·	I · ·	P · — — ·	W · — —
C — · — ·	J · — — —	Q — — · —	X — · · —
D — · ·	K — · —	R · — ·	Y — · — —
E ·	L · — · ·	S · · ·	Z — — · ·
F · · — ·	M — —	T —	
G — — ·	N — ·	U · · —	

Tables for Reducing other Measures to the Metrical Measures of the Centimètre-gramme-second (C. G. S.) and Mètre-gramme-second, or Absolute Systems. By Paget Higgs.

The relations of linear, superficial, and capacity measures are given elsewhere.

Velocity:—

1 foot a second = 30·4797 cm. or ·3048 m. a second.
1 statute mile an hour = 44·704 cm. = ·447 m. a second.
1 nautical mile or knot an hour = 51·453 cm. = ·5145 m. a second.
1 kilomètre an hour = 27·777 cm. = ·278 m. a second.

Density:—

Pure water at 4° C. = 1·000013 grm. a cub. cm.
1 lb. a cubic foot = ·016019 „ „

Force:— ($g = 981.$)

The C. G. S. unit of force is called the dyne, and is the force which acting upon a gramme for a second, generates a velocity of a centimètre a second; or is the force which acting upon a gramme produces the C. G. S. unit of acceleration; or upon any mass for 1 second produces the C. G. S. unit of momentum.

The M. G. S. unit of force = 100 dynes.

Force—*continued.*

The weight of 1 gramme = 981 dynes.
" 1 grain = 63·57 "
" 1 oz. avoir. = $2 \cdot 78 \times 10^4$ dynes.*
" 1 lb. " = $4 \cdot 45 \times 10^5$ "
" 1 cwt. = $4 \cdot 98 \times 10^7$ "
" 1 ton = $9 \cdot 97 \times 10^8$ "
One poundal = 13,825 dynes.

Work or Energy:—

The C. G. S. unit of work or energy is called the erg; and is the amount of work done by a dyne working through a distance of a centimètre.

1 gramme-centimètre = 981 ergs.
1 gramme-mètre = 981×10^2 ergs.
1 kilogrammètre = 981×10^5 "
1 milligram-millimètre = ·0981 "
1 foot-pound = $(13825 \times g) = 1 \cdot 356 \times 10^7$ ergs.
1 foot-poundal = 421,390 ergs.
1 foot-ton = $3 \cdot 04 \times 10^{10}$ ergs.
1 horse-power = $7 \cdot 46 \times 10^9$ ergs a sec.

Pressure:—

1 pound a square foot = 479 dynes a sq. cm.
1 pound a square inch = $6 \cdot 9 \times 10^4$ "
1 kilogramme per sq. m. = 98·1 "
760 mm. mercury at 0° C. = $1 \cdot 014 \times 10^6$ "
30 ins. " " = $1 \cdot 0163 \times 10^6$ "

Heat:—

1 gramme-degree Cent. = $4 \cdot 2 \times 10^7$ ergs.
1 pound-degree " = $1 \cdot 91 \times 10^{10}$ "
1 " Fahr. = $1 \cdot 06 \times 10^{10}$ "

Electricity:—

1 volt-weber = $\frac{1}{746}$ HP. = 10^7 ergs.

* To avoid confusion in writing numerous ciphers, this notation has been generally adopted; 10^n means 10 to the nth power, or 1 with as many ciphers after as n indicates; thus $10^4 = 10{,}000$.

Construction of Electromagnets.

Let a = thickness of magnetizing helix.
b = total length of the two bobbins.
c = diameter of core.
g = diameter of covered wire in mètres.
f = constant, varying generally from 1·4 with fine wires to 1·2 with moderately coarse wires, but dependent on the nature of the covering.
A = attractive force in fundamental units.
P = attractive force in grammes at 1 mm. distance.
E = electromotive force of current in Daniell's cells.
H = length of magnetizing helix, in mètres.
I = quantity of current, measured as E acting on m mètres of telegraph wire of 4 mm. diameter; or as hundredths of a weber; or as in G. M. S. units.
t = number of convolutions.
R = resistance in mètres of telegraph wire of exterior circuit, including that of the source of electricity (100 mètres = 1 ohm).
F = magnetic moment.
$q = \dfrac{\text{conductivity of R}}{\text{conductivity of H}}$.
k = 0·1722 when E is in Daniell cells and R is in mètres of telegraph wire; = ·015957 when E and R are in B. A units.
n = number of cells of battery.
e = e. m. f. of each cell.
ρ = resistance of each cell.

ELECTROMAGNETS—*continued.*

Let r = resistance of connections of battery system.

$$t = \frac{a\,b}{g^2}.$$

$$\mathrm{H} = \frac{\pi\,b\,a\,(a+c)}{g^2}.$$

$$\mathrm{F} = \frac{\mathrm{E}\,t}{\mathrm{R}+\mathrm{H}} = \frac{\mathrm{E}\,a\,b}{\mathrm{R}\,g^2 + \pi\,b\,a\,(a+c)}.$$

$$\mathrm{A} = \frac{\mathrm{E}^2\,t^2}{(\mathrm{R}+\mathrm{H})^2} = \frac{\mathrm{E}^2\,a^2\,b^2}{[\mathrm{R}\,g^2 + \pi\,b\,a\,(a+c)]^2}.$$

Reduced value of R [relatively to H taken as resistance, in mètres of helix] $= \frac{q\,\mathrm{R}\,g^2}{f^2}$; in which case, as H will vary as g^4 instead of as g^2,

$$\mathrm{F} = \frac{f^2\,g^2\,\mathrm{E}\,a\,b}{q\,\mathrm{R}\,g^4 + f^2\,\pi\,b\,a\,(a+c)};$$

$$\mathrm{A} = \frac{f^4\,g^4\,\mathrm{E}^2\,a^2\,b^2}{[q\,\mathrm{R}\,g^4 + f^2\,\pi\,b\,a\,(a+c)]^2};$$

$$\frac{g}{f} = \text{diameter of bare wire.}$$

Maxima Conditions.

As to resistance of helix:—For electromagnets of equal dimensions that size of wire is best which makes resistance of helix = R. But taking account of the thickness of insulating covering, the resistance of the helix should be to R as diameter of bare wire is to that of same wire covered.

ELECTROMAGNETS—*continued.*

Between several coils wound with same wire but with different numbers of convolutions, for a circuit of given resistance, that will be best, the resistance of which is to R as $a + c : a$.

As to a and c:—a should $= c$; $b = 12$.

$$\text{H then} = \frac{75 \cdot 4\, c^3}{g^2}, \text{ and } t = \frac{12\, c^3}{g^2}.$$

Where $\mathrm{R} = \mathrm{H}$; $a = c$; $b = m\,c$;

$$\frac{q\,\mathrm{R}\,g^2}{f^2} = \frac{2\,\pi\,c^3\,m}{g^2}, \text{ and } g^4 = f^2\,\frac{c^3}{\mathrm{R}} \cdot \frac{2\,\pi\,m}{q}.$$

As $\dfrac{\text{conductivity of iron wire}}{\text{conductivity of copper wire}} = 6$; and diam. of 4 mm. wire $= \cdot 000016$ m.; $q = \dfrac{6}{\cdot 000016} = 375000$, and $\dfrac{2\,\pi\,m}{q} = \cdot 00020106$; whence

$$g = \sqrt{f\sqrt{\frac{c^3}{\mathrm{R}}} \cdot \cdot 00020106}.$$

With relation to b:—

$$\mathrm{A} = \frac{\mathrm{E}^2\,m^2\,c^4\,c^{\frac{3}{2}}}{[\mathrm{R}\,g^2 + 2\,\pi\,c^3\,m]^2}.$$

With relation to c:—

$$c = \frac{\mathrm{E}}{\sqrt{\mathrm{R}}}.\mathrm{K}.$$

With relation to P:—

$$\mathrm{P} = \frac{\mathrm{I}^2\,t^2\,c^{\frac{3}{2}}}{\cdot 00008555}.$$

x 2

ELECTROMAGNETS—*continued.*

With relation to the battery:—

Let the accentuated quantities represent the values from a typical electromagnet; then

$$\frac{n\,e}{n'\,e'} = \frac{\sqrt{n\,\rho + r}}{\sqrt{n'\,\rho + r'}}.$$

$$\frac{n^2\,e^2}{n\,\rho + r} = \left(\cdot 0225\,\sqrt[3]{\sqrt{f^4\,P^2}}\right)^2 = M;\ \text{and}$$

$$n = \frac{M^2\,\rho}{2\,e^2} + \sqrt{\left(\frac{M^2\,\rho}{2\,e^2}\right)^2 + \frac{M^2\,r}{e^2}}.$$

If i represent the number of series and h the number of each member of the series in parallel arc, the internal resistance becomes $\frac{i}{h}\cdot\rho$ and

$i\,h = \frac{\rho}{e^2}\cdot M.$ Under these conditions,

$$c = e\,\frac{\sqrt{h\,i}}{\sqrt{\rho}} \times 0\cdot 173.$$

Derivations.

If x be the number of derivations from the same pole of the battery, the value of $h\,i$ or of n will be the same as in the simple case, but multiplied by x.

For circuits of equal resistances the diameter of the electromagnet should be proportional to the e. m. f.

For equal e. m. f. the diameter varies as $\sqrt{\text{total res.}}$

For equal diameter, E α $\sqrt{\text{res.}}$

For given electromagnetic force, E α $\sqrt{\text{res.}}$

TELEGRAPH CONSTRUCTION.

(By R. S. Brough, Esq., M.S.T.E., Indian Telegraph Department.)

§ I. The Wire.

Let T = breaking strain of the wire; w = weight of unit of length of the wire; L = length of itself it can just support without breaking. Then $L = \frac{T}{w}$ an absolute length which is constant for any the same kind and quality of wire; and whose numerical value depends only on the unit of length adopted. For the ordinary soft iron wire employed in overland telegraphy,* $L = 3\frac{1}{3}$ miles.

Let t = working strain of the wire; l = length of the wire whose weight is equal to its working strain; and z = factor of safety; so that $t = \frac{T}{z}$ and $l = \frac{L}{z}$; then $l = \frac{t}{w}$. When $z = 4$, $l = 4400$ feet for soft iron wire.

Cartesian equation to the *Catenary*, the origin being at a distance c below the vertex of the curve·

$$y = \frac{c}{2}\left(\epsilon^{\frac{x}{c}} + \epsilon^{-\frac{x}{c}}\right).$$

Approximate equation to the *Catenary:*

$$x^2 = 2c\,(y - c) - \tfrac{1}{3}\,(y - c)^2.$$

* The strength of wire is extremely variable, depending essentially on *quality* and *temper*, and it ranges from soft iron wire, which will carry 3 miles of itself, up to steel pianoforte wire, which will carry 16 miles of itself.

Telegraph Construction, by R. S. Brough—*continued*

Equation to the *Parabola:*

$$x^2 = 2c(y - c).$$

In the neighbourhood of its vertex, the catenary differs but little from the parabola, whose focal distance is equal to half the modulus of the catenary.

Let p = strain at the vertex, then $c\,w = p$.

The strain at any point of the catenary is found from the equation $t = y\,w$. Hence the strain at the lowest point is least; and the strain at any other point is equal to the strain at the lowest point plus the weight of a piece of the wire, whose length is equal to the height of the point in question above the lowest point.

In telegraphy it is the maximum strain, or that *at the insulator*, which is kept constant, and therefore the strain at the lowest point is variable. Hence we have frequently to deal with catenaries of different parameters.

Firstly. *When the points of support of the wire are on the same level.*

Let a = the length of the span.
d = the "dip" of the wire, or versed-sine of the curve.
p = the strain at the lowest point of the curve.
t = the strain at the insulator.
w = the weight of the wire per unit of length.
s = the length of the wire in the span.

Telegraph Construction, by R. S. Brough—*continued.*

Let i = the angle made by the wire with the horizon at the insulator.

$c = \frac{p}{w}$ = modulus of the catenary.

$l = \frac{t}{w}$ = the ordinate of the curve at the insulator.

Modulus of Catenary.

$$l = c + \frac{a^2}{8\,c} + \frac{a^4}{384\,c^3} + \ldots,$$

$$d = \frac{a^2}{8\,c} + \frac{a^4}{384\,c^3} + \frac{a^6}{46080\,c^5} + \ldots.$$

Approximately,

$$c = \frac{1}{7}\left\{4\,l + \sqrt{(3\,l)^2 - 21\left(\frac{a}{2}\right)^2}\right\}$$

$$= \frac{a^2}{8\,d} + \frac{c}{6} \text{ nearly.}$$

Dip.

Given a and l, required d,

$d = l - c.$

Approximately,

$$d = \frac{1}{7}\left\{3\,l - \sqrt{(3\,l)^2 - 21\left(\frac{a}{2}\right)^2}\right\}$$

$$= \frac{a^2}{8\,l} \text{ nearly.}$$

Hence (1) the dip is rigidly the same for all gauges of any the same kind and quality of wire

Telegraph Construction, by R. S. Brough—*continued.*

and that (2) the dip varies approximately as the square of the length of the span.

Roughly, for iron wire,

$$d = \left(\frac{a \text{ yards}}{100}\right)^2 \times 2{\cdot}56 \text{ feet.}$$

For maximum span $d = \frac{a}{3}$.

Strain at Insulator.

Given a and d, required l,

$l = c + d$.

Approximately,

$$l = \frac{a^2}{8\,d} + \frac{7\,d}{6}$$

$$= \frac{a^2}{8\,d} \text{ nearly.}$$

Angle at Insulator.*

$$\tan. i = \frac{a}{2\,c} + \frac{a^3}{48\,c^3} + \frac{a^5}{3840\,c^5} + \ldots.$$

Approximately,

$$\tan. i = \frac{3\,a}{2\sqrt{(3\,c)^2 - 3\left(\frac{a}{2}\right)^2}}$$

$$= \frac{4\,d}{a} \text{ nearly.}$$

Length of wire in span.†

$$s = a + \frac{a^3}{24\,c^2} + \frac{a^5}{1920\,c^4} + \ldots.$$

Approximately,

$$s = \sqrt{a^2 + \frac{16}{3}\,d^2}$$

$$= a + \frac{8\,d^2}{3\,a} \text{ nearly.}$$

* Can be measured by the "inclinometer" or "batter level."

Telegraph Construction, by R. S. Brough—*continued.*

Increment of dip due to small increment of length.	$d = \sqrt{\frac{3}{8} a (s - a)}$ $\delta d = \frac{3 a}{16 d} \delta s$
Elongation of wire from straining.	$s' = s\left(1 + \frac{k}{z}\right)$

where

$$k = \frac{\text{Breaking strain per unit of area}}{\text{Modulus of elasticity per unit of area}}$$

$$= \frac{57000 \text{ lbs. per sq. in.}}{25000000 \text{ lbs. per sq. in.}} \text{ for soft iron wire}$$

$$= 0 \cdot 0023.$$

Roughly, iron stretches about $\frac{1}{10000}$ of its length within a strain of 1 ton per square inch.

When $z = 4$, $\delta s = 0 \cdot 000575 s$ or about 2 inches per 100 yards.

Effect of change of temperature.	$s' = s(1 \pm n f) \{ 1 + e (t' - t) \}$

where f = the coefficient of dilatation.
$= 0 \cdot 00001235$ per 1° C.
n = number of degrees through which temperature changes.
e = reciprocal of modulus of elasticity.
$= 0 \cdot 00000004$.

In 100 yards span the dip varies about 1 inch per 6° Fah. change of temperature.

Telegraph Construction, by R. S. BROUGH—*continued.*

SECONDLY. *The points of support of the wire are on different levels.*

Let b = the difference of levels and l = the ordinate of the curve at the higher point of support, then $(l-b)$ = ordinate at lower point of support; and the modulus c can be found by a series of approximations from the equation:

$$a = c \log._{\epsilon} \frac{\left\{ l + \sqrt{l^2 - c^2} \right\} \left\{ (l-b) + \sqrt{(l-b)^2 - c^2} \right\}}{c^2}$$

The distance of the lowest point of the curve from the lower support is given by

$$x = c \log._{\epsilon} \frac{(l-b) + \sqrt{(l-b)^2 - c^2}}{c}$$

Approximately,

$$x = \frac{3a(21a^2 + 25b^2 - 18bl) - 2b\sqrt{3\left\{ 24a^2(11b^2 + 18l^2) - 7(36a^4 + 27a^2bl + 4b^4) \right\}}}{6(21a^2 + 25b^2)}$$

$$= a\,\frac{2(a^2 + b^2 - bl) - b\sqrt{2\left\{ 2l(l-b) - a^2 \right\}}}{2(2a^2 + b^2)}$$

$$= \frac{a}{2} - \frac{b(l-b)}{a} \text{ nearly.}$$

Telegraph Construction, by R. S. Brough—*continued.*

Having found the position of the lowest point of the curve, all the other particulars of the curve can be found by the preceding formulæ.

§ II. Strains produced by Wire.

Straight Line.—The whole vertical pressure on the supports of any line is obviously equal to the whole weight of the wire on the line. When the points of support are on the same level, and the spans are equal, the vertical pressure on any one support is equal to the weight of wire in one span. In erecting an "un-checked" wire, we have practically to deal with the case of a chord passing over smooth pulleys, and hence the strains *along the wire* on opposite sides of the support are always equal. The resultant horizontal strain, if any, is therefore

$$P = (\cos. i - \cos. i')\, t,$$

where i and i' are the angles made by the wire with the horizon on opposite sides of the support. If, however, the supports be on the same level, and the spans be equal, then $i = i'$, and the resultant horizontal strain is nil.

When the supports are not on the same level, the distance to set them apart in order to make $i = i'$ can be calculated.

Angles.—Let θ = the angle contained by the wire.

ϕ = the supplement of the same.

R = the resultant strain due to the wire.

Then

$$R = 2\, t \cos. \frac{\theta}{2} = 2\, t \sin. \frac{\varphi}{2} = t\sqrt{2\,(1 - \cos. \phi)}.$$

Telegraph Construction, by R. S. BROUGH—*continued.*

By means of these formulæ the maximum angle admissible with an insulator of given strength when employed to support a wire of given weight can be calculated, thus: *

$$\phi = 2 \sin.^{-1} \frac{R}{2t}.$$

Terminals.—The horizontal strain on a terminal insulator due to the wire is

$$\begin{aligned} P &= t \cos. i \\ &= t \quad \text{approximately.} \end{aligned}$$

III. STRENGTH OF POSTS.

Let P be the resultant strain at right angles to the post, whether due to change of direction of alignment, wind pressure, terminating of wires, &c., and let h be the height of the centre of pressure above the ground line, then the strength m required at the ground line must be at least such that m is not $< P \times h$.

If z be the factor of safety adopted, then

$$\frac{m}{z} = P . h$$

The strength of a post depends (1) on the form

* Measure radius = 57·3 feet from bottom of post; then, the number of feet in chord will approximately give the number of degrees in angle.—(W. P. JOHNSTON.)

Telegraph Construction, by R. S. Brough—*continued.*

of its cross-section, and (2) on the material of which it consists.

Let d = depth of the post in direction of strain.
b = width of the post at right angles to strain.

Then, generally,

Strength of Posts.
$$\begin{cases} m = k \,.\, \dfrac{f}{d} \,.\, b\,d^3 \text{ for solid posts,} \\[2ex] m = k \,.\, \dfrac{f}{\mathrm{D}} \,.\, (\mathrm{B\,D}^3 - b\,d^3) \text{ for hollow posts of uniform thickness,} \end{cases}$$

where k is a coefficient depending on the form of the cross-section, and f a coefficient depending on the material of which the post consists.

For rectangles (including squares), $k = \frac{1}{6}$.

For isosceles triangles (including equilateral triangles), $k = \frac{1}{24}$.

For ellipses (including circles), $k = \frac{\pi}{32} = \frac{1}{10 \cdot 2}$.

In the case of *thin* hollow posts,

$$m = 2\,k \,.\, f \,.\, t \,.\, \mathrm{D} \,.\, (\mathrm{D} + 3\,\mathrm{B})$$

where t = thickness of the material.

The following are the values of the "modulus of rupture" in tons per square inch:*

* The modulus of rupture is eighteen times the load which is required to break a bar of 1 inch square, supported at two points 1 foot apart, and loaded in the middle.

Telegraph Construction, by R. S. BROUGH—*continued.*

MATERIAL.	Values of f in tons per square inch.
WROUGHT IRON (Clark).	
Solid bars, and circular welded tubes ..	18 to 20
Circular riveted tubes of plate iron, with transverse joints double riveted	13
Plate beams	18
CAST IRON (Clark).	
Solid bars	13
Tubes	11
WOOD (Rankine).	
Fir: Red Pine	3 to 4
„ Spruce	4 „ 5
„ Larch	2 „ 4
Saul	7 „ 10
Teak	6 „ 9

Posts of uniform strength may be designed by means of the following formulæ, x being the depth of the post in the direction of the strain at the ground line, and d its depth at the top:

For solid posts.

$$\left\{\begin{array}{l} P \,.\, h = k \,.\, \frac{f}{x} \,.\, b\, x^3, \\ d = \frac{x}{2} \text{ if } b \text{ be kept constant,} \\ d = \frac{3}{2} x \text{ if } b \text{ vary with } x. \end{array}\right.$$

Telegraph Construction, *by* R. S. BROUGH—*continued.*

For *thin* hollow posts of uniform thickness.
$$\left\{\begin{array}{l} \mathrm{P}\,.\,h = 2\,k\,.\,f\,.\,t\,.\,x\,(x + 3\,\mathrm{B}) \\ d = \dfrac{x^2}{2\,x + 3\,\mathrm{B}} \text{ if B be kept constant,} \\ d = \dfrac{x}{2} \text{ if B vary with } x. \end{array}\right.$$

§ IV. STAYS, STRUTS, &C.

Let P = the horizontal strain to which a post is subjected, and h = the height of P above the ground; then the resultant moment about the ground line is $m = \mathrm{P}\,.\,h$.

If the post be sloped through an angle α, away from the direction of the strain, then the moment is reduced to $m = \mathrm{P}\,.\,h \cos.\,\alpha$.

If P be the resultant of any number of strains $p\,p'\,p'' \ldots$ acting at height $h\,h'\,h'' \ldots$ above the ground line, the place of application of the stay is given by the equation

$$\bar{x} = \frac{\Sigma\,(p\,.\,h)}{\Sigma\,(p)},$$

and the strain on the stay $= \dfrac{\Sigma\,(p)}{\cos.\,\theta}$ where θ is the angle it makes with the horizon.

If the stay be applied below $\bar{x}$ at a height y above the ground, then $\Sigma\,(p)$ exerts a moment $= \{\,\Sigma\,(p)\,(\bar{x} - y)\,\}$ about the place of application of the stay, tending to bend the post at that point.

Telegraph Construction, by R. S. BROUGH—*continued.*

If the stay be applied above $\bar{x}$ at a height y' from the ground, then $\Sigma(p)$ will have a moment $\left\{ = \Sigma(p) \frac{\bar{x}(y' - x)}{y'} \right\}$ about the place of application of the stay, tending to bulge the post below that point.

The stay should be always fixed in the vertical plane in which the resultant strain acts. If the resultant strain in one direction be $\Sigma(p)$, and the resultant strain in another direction be $\Sigma(q)$ making an angle α with the former direction, and R be the whole resultant strain, the direction of which makes an angle β with the first direction, then $R^2 = \{\Sigma(p)\}^2 + \{\Sigma(q)\}^2 + 2\{\Sigma(p)\}\{\Sigma(q)\} \cos. \alpha$; and $\sin. \beta = \frac{\Sigma(q)}{R} \sin. \alpha$.

§ V. PRESSURE OF WIND AND WATER.

If the pressure on a flat surface of *unit* length and width a at right angles to the current be P, the pressure on a surface whose section is a right triangle on the same base a is $= \frac{P}{2}$, and the pressure on a surface whose section is semicircular on the same base a is $= \frac{2}{3}P$; but practically in the last case the resistance has been found to be about $= \frac{3}{4}P$.

A fairly safe maximum wind pressure to be allowed for is 50 lbs. on the square foot.

Telegraph Construction, by R. S. Brough—*continued.*

Let p = the pressure per unit of length of the wire.

Then the strain on the wire at the insulator will be

$$t' = \left(\frac{a^2}{8\,d} + \frac{7\,d}{6}\right)\sqrt{w^2 + p^2},$$

or

$$t' = \frac{a^2\sqrt{w^2 + p^2}}{8\,d} \text{ nearly.}$$

If t' = the new strain on the wire and t = the original strain on the wire, then

$$t' = \sqrt{1 + \left(\frac{p}{w}\right)^2} \times t \text{ nearly.}$$

ELECTRICAL FORMULÆ, &c.

By Paget Higgs, LL.D., C.E., *and* R. S. Brough.

1. *Units.* (*Electromagnetic.*)

Ohm: Unit of resistance = 10^7 mètre-second units.

Volt: „ potential = 10^5 mètre-gramme-second units.

Weber: „ quantity = 10^{-2} mètre-gramme units.
„ current = 10^{-2} mètre-gramme-second units.

Farad: „ capacity = 10^{-7} mètre-second units.

Electrical Formulæ, by PAGET HIGGS, LL.D., C.E., *and* R. S. BROUGH—*continued.*

2. *The measurement of resistance.*

In the following let a and b be resistances in ratio-arms of bridge, w balancing, and x unknown resistance.

i. By Wheatstone's Bridge:

$$x = \frac{b}{a} \cdot w.$$

When measures with $\pm$ currents differ slightly, and w' is reading with $+$ current, and w'' reading with $-$ current towards a and b,

$$x = \frac{b}{a} \cdot \frac{w'' + w'}{2}.$$

If the difference is greater,

$$x = \frac{b}{a} \cdot \left\{ \frac{w'' + w'}{2} - N \frac{w'' - w'}{2} \right\},$$

let E = e. m. f. of battery, and e that in one of the sides,

$$e = N E,$$

where

$$N = \frac{b\,(w'' - w')}{b\,(w'' + w) + 2\,\{a\,b + f\,(a + b)\}},$$

Neglecting f, the battery resistance,

$$N = \frac{w'' - w'}{w'' + w' + a}.$$

ii. By the differential galvanometer:

$$x = \frac{n}{n'} \cdot w,$$

Electrical Formulæ, *by* PAGET HIGGS, LL.D., C.E., *and* R. S. BROUGH—*continued.*

$$x = \frac{(w'' + w')\,\{\,g + f(n + n')\,\} + 2\,n\,w'w''}{2\,\frac{n'}{n}\,\{\,g + f\,(n + n')\,\} + n'\,(w'' + w')},$$

$$e = \frac{n\,(w'' - w')}{2\,\{\,g + f\,(n + n')\,\} + n\,(w'' + n')}\,\mathrm{E},$$

where

$$n = 1 + \frac{g}{s} \text{ and } n' = 1 + \frac{g}{s'},\ g = \text{galv., and}$$

$$s = \text{shunt resistance.}$$

iii. By deflection method:

$$x = \frac{1}{n'}\left[\frac{\mathrm{F}\,(d)}{\mathrm{F}\,(d')} \cdot \frac{\mathrm{E}'}{\mathrm{E}} \cdot \{\,n\,(f + w) + g\,\} - g\right] - f',$$

where w is known resistance in circuit with deflection d, f, g, n, and E; x is resistance with deflection d', f', g, n', and E′.

If the resistances taken with ± currents differ, the true resistance is

$$x = 2\,\frac{x_1\,x_2}{x_1 + x_2}.$$

When measuring great resistances,

$$x = \frac{n}{n'} \cdot \frac{\mathrm{F}\,(d)}{\mathrm{F}\,(d')} \cdot \frac{\mathrm{E}'}{\mathrm{E}} \cdot (f + w).$$

When

$$s = s' = \infty,\ n = n' = 1,$$

and

$$x = \frac{\mathrm{F}\,(d)}{\mathrm{F}\,(d')} \cdot \frac{\mathrm{E}'}{\mathrm{E}} \cdot (f + g + w) - (f' + g).$$

Electrical Formulæ, by Paget Higgs, LL.D., C.E., *and* R. S. Brough—*continued.*

3. *The comparison of electromotive forces.*

i. By the deflection method:

$$\frac{E'}{E} = \frac{F(d')}{F(d)} \cdot \frac{n'(f' + w') + g}{n(f + w) + g}.$$

When $s = s' = \infty,\ n = n' = 1,$

and $$\frac{E'}{E} = \frac{F(d')}{F(d)} \cdot \frac{f' + w' + g}{f + w + g}.$$

ii. By the condenser method:

$$\frac{E'}{E} = \frac{\sin.\frac{d'}{2}}{\sin.\frac{d}{2}} \cdot \frac{n'}{n}.$$

With the reflecting galv. d' and d may be put for $\sin.\frac{d'}{2}$ and $\sin.\frac{d}{2}$.

iii. By Poggendorff's method: (Put $b = \infty$ in the bridge, and intercalate E in branch x):

$$\frac{E'}{E} = \frac{a + f' + w}{w} = \frac{(w - w') + (a - a')}{w - w'}.$$

4. *Measurement of the internal resistance of batteries.*

i. By the deflection method:

$$f = \frac{F(d').(n'w' + g) - F(d).(nw + g)}{n.F(d) - n'.F(d)}.$$

Electrical Formulæ, by PAGET HIGGS, LL.D., C.E., *and* R. S. BROUGH—*continued.*

When

$s = s' = \infty, n = n' = 1$, and

$$f = \frac{F(d').(w'+g) - F(d).(w+g)}{F(d) - F(d')}.$$

ii. By Poggendorff's method:

$$f = \frac{w(a+w') - w(a'+w)}{w+w'}.$$

iii. By Thomson's method: (Shunt the battery f with shunt s, and take reading through resistance w; remove the shunt, and increase the resistance to w' so that the original deflection is again produced. In the bridge make $b = o$, $x = \infty, a =$ shunt, $w =$ resistance):

$$f = s\,\frac{w' - w}{w + g}.$$

If we take $s = w + g$, then $f = w' - w$.

By condenser or electrometer method: Connect battery with condenser or electrometer electrodes (if with condenser as in taking discharge), take deflection d; shunt battery with w, and take d'.

$$f = w\left(\frac{d}{d'} - 1\right).$$

iv. By the differential galvanometer (Latimer Clark):

$f = w' - 2w$. When $w = o, f = w'$.

Electrical Formulæ, *by* PAGET HIGGS, LL.D., C.E., *and* R. S. BROUGH—*continued.*

5. *The comparison of capacities.*

$$\frac{S'}{S} = \frac{\sin.\frac{d'}{2}}{\sin.\frac{d}{2}} \cdot \frac{n'}{n} \cdot \frac{E'}{E}.$$

With the reflecting galv. d' and d may be put for $\sin.\frac{d'}{2}$ and $\sin.\frac{d}{2}$.

Standard-jar method: Let a = first discharge and a_n = nth discharge deflection of standard condenser charged from S to be measured; κ = capacity of standard condenser; then

$$S = \kappa \cdot \frac{\sqrt[n]{a_n}}{\sqrt[n]{a} - \sqrt[n']{a_n}}.$$

6. *Line Testing.* (Schwendler.)

Let W = measured circuit resistance.
w = measured conduction resistance.
I = measured insulation resistance.

Then the following inequality must hold,

$$w < W < I.$$

Let i = true insulation resistance.
L = true conduction resistance of whole line.
l = true conduction resistance up to resultant fault.
r = true resistance of receiving instrument at distant station, corrected for temperature.

Electrical Formulæ, by Paget Higgs, LL.D., C.E., *and* R. S. Brough—*continued.*

Then

$$i = \sqrt{\frac{(I - W)(I - w)\,r}{W - w}},$$

$$L = I + \frac{(I - W)\,r}{W - w} - 2\,i,$$

$$l = I - i,$$

and $\frac{l}{L}$ should be positive and less than unity.

When $l = \frac{L}{2}$, $i = \sqrt{I\,(I - w)}$, $L = 2\,(I - i)$

and $\frac{I\,(W - w)}{I - W}$ should be $= r$.

Let n = number of miles the line is in length, then insulation per mile $= n \times i$.

Let m = the "reduced length" of the line in terms of the standard wire, then conductor resistance per mile $= \frac{L}{m}$.

7. *Fault Testing.*

i. Earths.

(*a*) Single Line.

Blavier's Formula:

$$x = w - \sqrt{(I - w)(L - w)}.$$

Schwendler's Formula:

$$x = I - \sqrt{\frac{(I - W)(I - w)\,r}{W - w}}.$$

Electrical Formulæ, by Paget Higgs, LL.D., C.E., *and* R. S. Brough—*continued.*

(*b*) Double Line.

Loop test. (Loop $= w''$; localization $= w'$.)

$$x = \frac{a'\,b''\,w'' - a''\,b'\,w'}{a''\,(a' + b')}.$$

When

$$a'' = a' = a, \text{ and } b'' = b' = b,\ x = \frac{b\,(w'' - w')}{a + b}.$$

When $a = b$, $x = \dfrac{w'' - w'}{2}$.

Correction for "partial" earth (Schwendler):

Let $d = \dfrac{\text{resistance of fault to be localized}}{\text{resistance of resultant fault}}$.

Then $x = \dfrac{a\,w'' - b\,w'}{a + b}\,(1 + d) - \dfrac{d\,w''}{2}$.

When $a = b$, $x = \dfrac{w'' - (1 + d)\,w'}{2}$

By capacity (cable):—

X = true resistance to break; R = measured resistance of cable and break; k = capacity per unit of conductor resistance, or total capacity ÷ total resistance when fault free; f = resistance of battery; g of gals.; d = discharge deflection from cable; D from condenser of 1 unit cap.;

$$X = R - \sqrt[3]{R^3 - \frac{3\,d}{D\,k}\,(g + R)\,(f + R)}$$

If resistance of break = *o*, two-thirds of charge return to charging end.

Electrical Formulæ, by PAGET HIGGS, LL.D., C.E., *and* R. S. BROUGH—*continued.*

If discharge reading (d) is in same direction as permanent deflection p, true discharge

$$= \sqrt{d^2 - 2\,d\,p}$$

$$\text{if opposite} = \sqrt{d^2 + 2\,d\,p}$$

ii. CONTACTS.

(a) When a third wire is not available (Schwendler): (Distant ends looped $= w'$; distant ends insulated $= w''$.)

$$x = \frac{w' - \sqrt{L' + L'' - w'(w'' - w')}}{m' + m''},$$

where L′ and L″ are the absolute, and m' and m'' the per mile resistances of the two wires in contact.

When $w' = w'' = w$, $x = \dfrac{w}{m + m'}$.

When $m' = m'' = m$, $x = \dfrac{w}{2\,m}$.

(b) When a third wire is available (Higgins): Put one of the wires in contact to earth, and localize the "contact" as an "earth" by the loop test. *See* 7 i. (b).

iii. DISCONNECTIONS.

(a) By the insulation method:

$$x = \frac{I}{i} \cdot L.$$

Electrical Formulæ, by PAGET HIGGS, LL.D., C.E., *and* R. S. BROUGH—*continued.*

(*b*) By the capacity method:

$$x = \frac{s}{S} . L,$$

where S = total capacity when fault free, and s = measured capacity, L being length of line.

8. When a line contains several different gauges of wire, to find the resistance per mile of any particular gauge (Schwendler):

$$x_a = \frac{L}{d^2{}_a \, \Sigma^n{}_1 . \frac{l}{d^2}},$$

where d_a = the diameter of the wire whose resistance is required.

9. The insulation of any cable is

$$I = \frac{k}{2 \pi l} \log._{\epsilon} \frac{D}{d} \text{ megohms}$$

$$= 0 \cdot 3665 \frac{k}{l} \log. \frac{D}{d} \text{ megohms,}$$

where k is the resistance in megohms of a cubic unit of the insulating material.

When the knot = 2029 yards is the unit of length, k = 2100 megohms at 75° F. for gutta-percha, k = 40950 megohms at 75° F. for Hooper's core. The insulation of any guttapercha cable is p (log. D − log. d) megohms per knot at 75° F., where p varies from 700 to 300, according to the insulating property of the g.p. coating. As a

Electrical Formulæ, by PAGET HIGGS, LL.D., C.E., *and* R. S. BROUGH—*continued.*

broad rule g.p. having high insulating properties, has also high inductive capacity.

10. The electrostatic capacity of any cable is

$$S = \frac{c\,l}{2\log._\epsilon \frac{D}{d}} \text{ electrostatic units,}$$

where $c = 1$ for air, $= 3 \cdot 1$ for Hooper's core, $= 4 \cdot 2$ for guttapercha.

$$S = 2 \cdot 7 \frac{s\,l}{\log. \frac{D}{d}} \text{ microfarads per } l \text{ knots,}$$

where s is the inductive capacity of a cubic knot of the dielectric.

$s = 0 \cdot 0687$ microfarad for guttapercha.

$s = 0 \cdot 0543$ microfarad for Hooper's core.

The electrostatic capacity in microfarads of a guttapercha cable is approximately per knot

$$= \frac{k}{\log. D - \log. d},$$

where k varies from $\cdot 1800$ to $\cdot 1400$, the lower number corresponding to the lower figure for insulation given in (9), and *vice versâ.*

11. The electrostatic capacity of an overland line is

$$S = \frac{l}{2\log._\epsilon \frac{4h}{d}} \text{ electrostatic units,}$$

Electrical Formulæ, by Paget Higgs, LL.D., C.E., *and* R. S. Brough—*continued.*

where d is the diameter of the wire, and h its height above the ground.

$$S = \frac{l}{24 \log. \frac{4h}{d}} \text{ microfarads per } l \text{ miles.}$$

12. To measure the insulation of a cable by its loss of charge (Werner Siemens):

$$I = 0 \cdot 4343 \frac{t}{S \log. \frac{V}{v}} \text{ megohms,}$$

where t is expressed in seconds and S in microfarads.

Res. per knot =

$$2 \cdot 13\, t \left(\frac{\log. \frac{D}{d}}{\log. \frac{V}{v}} \right) \text{ (in any units),}$$

where V and v are potentials, and D and d diameters in any units.

To measure insulation of a core, or cable, by direct deflection (Thomson galvanometer):

$$\left(\frac{R \left(\frac{g + s}{s} \right) d}{d^1} \right) l = \text{insulation}$$

in millions of units, where l = length in knots, d = deflection with battery and R millions units

Electrical Formulæ, by PAGET HIGGS, LL.D., C.E., *and* R. S. BROUGH—*continued.*

and $\frac{g+s}{s}$, and d^1 deflection with cable; g being galv., and s shunt resistance.

$$\left(\mathrm{R}\left(\frac{g+s}{s}\right)d\right) = \textit{constant} \text{ of instrument.}$$

13. The retardation characteristic of any cable is (Thomson)

$$a = \frac{k\,c\,l^2}{\pi^2} \log._\epsilon \left(\frac{4}{3}\right),$$

where l is its length, k its resistance, and c its capacity per unit of length in electrostatic units. The retardation is a minimum (for a given D) when $\mathrm{D} = 1 \cdot 649\, d$.

When k is expressed in ohms, c in microfarads, and l in knots (Jenkin),

$$a = \frac{0 \cdot 02332}{10^6} k\,c\,l^2 \text{ seconds;}$$

and the speed of signalling with mirror is, in words per minute (Clark and Sabine),

$$n = \frac{130{,}000{,}000}{k\,c\,l^2} \text{ through guttapercha cables;}$$

$$n = \frac{176{,}000{,}000}{k\,c\,l^2} \text{ through Hooper's cables.}$$

The speed of the Morse is about one-fifteenth that of Thomson's Mirror. Dot takes ·27 sec. at fifteen words per minute.

14. The weight of metal deposited from the

Electrical Formulæ, by PAGET HIGGS, LL.D., C.E., *and* R. S. BROUGH—*continued.*

solution of any of its salts by a current of C webers in t seconds is

$$n = 0{\cdot}00001\, a\, C\, t \text{ grammes,}$$

where a is the atomic weight of the metal referred to that of hydrogen as unity. One weber of electricity decomposes ·00142 grain of water.

A current strength which is measured in	must be multiplied by — to reduce it to — per minute:				
per minute	Cubic c.m. water-gases.	Milli-grams water.	Milli-grams copper	Milli-grams silver.	Magnetic units.
Cubic c.m. water-gases	..	0·5363	1·889	6·432	0·9579
Milligrams water ..	1·865	..	3·522	11·99	1·786
" copper ..	0·5294	0·2839	....	3·405	0·5071
" silver ..	0·1555	0·0834	0·2937	..	0·1489
Magnetic measure: $\frac{M.\,m.^{\frac{1}{2}}\ mgr.^{\frac{1}{2}}}{sec^{2}}$	1·044	0·5599	1·972	6·714	..

(*Kohlrausch.*)

15. The heat developed in a circuit of resistance r ohms in t seconds by a current of C webers is

$$H = 0{\cdot}2405\, C^2\, r\, t \text{ calories.}$$

16. The work done in a circuit of resistance r ohms in t seconds by a current of C webers is

$$W = 101{\cdot}92\, C^2\, r\, t \text{ grammètres.}$$

17. The electromotive force of Daniell's element

Electrical Formulæ, by PAGET HIGGS, LL.D., C.E., *and* R. S. BROUGH—*continued.*

= 1·079 volts; of Bunsen's = 1·88 volts; of Marié-Davy's = 1·524 volts; and of Leclanché's = 1·48 volts.

18. The resistance of one Siemens' mercury unit = 0·9536 ohm. (B. A. Report.) The resistance of one ohm = 1·0493 S. U.

19. Copper weighs about 559 lbs. per cubic foot. Sp. gr. 8·95.

A prism of pure copper one mètre long and one square millimètre in section weighs about 8·95 grammes; and its resistance is about 0·01642 ohm at 0° C., and increases about 0·388 per cent. per 1° C. (Maxwell.)

The resistance of a prism of pure copper one mètre long and weighing one gramme is about 0·14696 ohm at 0° C. The weight per knot of a telegraphic pure copper wire is 18430 d^2, d being taken in decimals of an inch. The diameter of a pure copper wire, weighing w lbs. per knot, is $7·366 \sqrt{w}$ mils. The resistance per knot of a pure copper wire, weighing w lbs., is $\frac{1192·45}{w}$ ohms, or $\frac{1250·4}{w}$ Siemens' units at 75° F.

20. Guttapercha weighs about 61 lbs. per cubic foot.

The resistance of a cubic knot of guttapercha is 2100 megohms at 75° F., and its capacity about 0·0687 microfarad. The weight of guttapercha

Electrical Formulæ, by PAGET HIGGS, LL.D., C.E., *and* R. S. BROUGH—*continued.*

per knot in any core is approximately $\frac{D^2 - d^2}{486}$ lbs., where D is outer and d inner diameter of g.p. sheath in mils. The diameter of a gutta-percha core with solid conductor weighing w lbs. per knot, and g.p. weighing W lbs. per knot, is $\sqrt{54 \cdot 3\, w + 486\, W}$ mils.

Let w' = resistance of guttapercha at $t'°$ F.,
w'' = resistance of guttapercha at $t''°$ F.,
then $\log. w'' = \log. w' - (t'' - t') \log. 0 \cdot 0399$.

21. Hooper's material weighs about $73\frac{1}{2}$ lbs. per cubic foot.

The resistance of a cubic knot of Hooper's material is 40950 megohms at 75° F., and its capacity about 0·0543 microfarad.

22. Iron weighs about 481 lbs. per cubic foot. Sp. gr. 7·7.

The resistance of a prism of soft iron one mètre long and one square millimètre in section is about 0·096 ohm at 0° C., and increases about 0·7 per cent. per 1° C.

The resistance of a prism of soft iron one mètre long and weighing one gramme is about 0·7392 ohm at 0° C.

The resistance of 100 yards No. 8 iron wire is roughly one ohm.

23. German silver weighs about 530 lbs. per cubic foot. Sp. gr. 8·5.

A prism of German silver one mètre long and

Electrical Formulæ, by PAGET HIGGS, LL.D., C.E., *and* R. S. BROUGH—*continued.*

one square millimètre in section weighs about 8·5 grammes; and its resistance is about 0·206 ohm at 0° C., and increases about 0·04 per cent. per 1° C.

The resistance of a prism of German silver one mètre long and weighing one gramme is about 1·75 ohms at 0° C.

24. The diameter d of any wire, whose specific gravity is s, and which weighs w grammes per mètre, is

$$d = 1 \cdot 12865 \sqrt{\frac{w}{s}} \text{ millimètres,}$$

and its sectional area a is

$$a = \frac{w}{s} \text{ square millimètres.}$$

25. The length of wire on a circular bobbin is

$$L = \frac{\pi b}{4 d^2} (A^2 - a^2),$$

where d = diameter of wire, including silk covering; b = length of bobbin; and A = outer diameter and a = inner diameter of bobbin.

Winding coils: Let c = specific conductivity of wire, that of pure copper being unity at 0° C.; l = average length of convolution in inches; m = area in square inches of a semi-section of the coil (that is the sectional area of the space to be filled with wire); s = thickness in inches of insulating covering; G = resistance of coil in ohms; r = radius

Electrical Formulæ, by Paget Higgs, LL.D., C.E., *and* R. S. Brough—*continued.*

of wire in inches; a = constant depending on method of coiling, generally = 4; γ = (constant) = ·0000001; d = diam. required in inches:

$$\text{then } G = \frac{\gamma\, l\, m}{2\, r^2\, (r + s)^2 c} = \frac{\cdot 0000002\, l\, m}{a\, r^2\, (r + s)^2 c};$$

$$r^2\,(r + s)^2 = \frac{\gamma\, l\, m}{2\, G\, c};\ r = \sqrt{\sqrt{\frac{\gamma\, l\, m}{2\, G\, c}} + \frac{S^2}{4}} - \frac{s}{2}$$

and as s is generally very small,

$$r = \sqrt[4]{\frac{\gamma\, l\, m}{2\, G\, c}} - \frac{s}{2} \text{ and } d = \sqrt[2]{\frac{\gamma\, l\, m}{2\, G\, c}} - s.$$

26. To test a telegraph *earth* (Schwendler):

Take two auxiliary earths, and measure the resistance between each of the three pairs of *earths*. (The mean of positive and negative readings to be taken.)

Let x be the required resistance, and a, b, and c the three observed resistances, then

$$x = \frac{a + b - c}{2}.$$

By the tangent galvanometer:

$$x = \frac{f + g}{2} \cdot \tan a^\circ \left(\frac{1}{\tan c^\circ} + \frac{1}{\tan d^\circ} - \frac{1}{\tan b^\circ} - \frac{1}{\tan e^\circ} \right)$$

where f and g are respectively = the resistances of the testing battery and galvanometer: and the deflections obtained are: with no external re-

Electrical Formulæ, by PAGET HIGGS, LL.D., C.E., *and* R. S. BROUGH—*continued.*

sistance $= a^\circ$; with leading wires only in circuit $= b^\circ$; with earth to be tested and first auxiliary earth $= c^\circ$; with earth to be tested and second auxiliary earth $= d^\circ$; and with two auxiliary earths $= e^\circ$. (The mean of the readings with positive and negative test currents to be taken.)

27. The best resistance for a receiving instrument on an overland line is (Schwendler)

$$r = \frac{5}{8} L,$$

where L = *true* conductor resistance of line.

The best resistance for a cable receiving instrument is $r = \frac{L}{4}$ for relays of medium sensitiveness.

28. Let the small letters be expressed in electrostatic units, and the large letters in electromagnetic units, then

$$\left.\begin{array}{ll} \text{Dimensions of } q : m^{\frac{1}{2}} l^{\frac{3}{2}} t^{-1} \\ \quad\text{,,} \qquad Q : m^{\frac{1}{2}} l^{\frac{1}{2}} \end{array}\right\} \frac{q}{Q} = v;$$

$$\left.\begin{array}{ll} \text{,,} \qquad c : m^{\frac{1}{2}} l^{\frac{3}{2}} t^{-2} \\ \text{,,} \qquad C : m^{\frac{1}{2}} l^{\frac{1}{2}} t^{-1} \end{array}\right\} \frac{c}{C} = v;$$

$$\left.\begin{array}{ll} \text{,,} \qquad r : l^{-1} t \\ \text{,,} \qquad R : l t^{-1} \end{array}\right\} \frac{r}{R} = \frac{1}{v^2};$$

Electrical Formulæ, by PAGET HIGGS, LL.D., C.E., *and* R. S. BROUGH—*continued.*

$$\left.\begin{array}{ll}\text{Dimensions of } e : m^{\frac{1}{2}}\, l^{\frac{1}{2}}\, t^{-1} \\ \quad ,, \qquad \mathrm{E} : m^{\frac{1}{2}}\, l^{\frac{3}{2}}\, t^{-2}\end{array}\right\} \frac{e}{\mathrm{E}} = \frac{1}{v};$$

$$\left.\begin{array}{ll} ,, \qquad s : l \\ ,, \qquad \mathrm{S} : l^{-1}\, t^{2}\end{array}\right\} \frac{s}{\mathrm{S}} = v^2.$$

$v =$ about 3×10^8 mètres per second.

29. The range of any receiving instrument is

$$\frac{\mathrm{C}'}{\mathrm{C}''} = \frac{p\,(q\,f + r + w)}{q\,(p\,f + r)},$$

where r = resistance of instrument; w = resistance added; f = resistance of mean cell; p = number of cells employed to produce strong current C′; and q = number of cells employed to produce weak current C″.

30. To correct wire resistance for temperature:

$$\mathrm{R}_{t'} = \frac{1 + (t' - 32)\,\alpha}{1 + (t - 32)\,\alpha}\,\mathrm{R}_t, \text{ Fahrenheit.}$$

$$\mathrm{R}_{t'} = \{\,1 + (t' - t)\,\alpha\,\}\,\mathrm{R}_t, \text{ Celsius.}$$

31. 1 sq. in. = 645·148 sq. mm.

log. 645·148 = 2·8096594.

1 sq. mm. = 0·00155 sq. in.

log. 0·00155 = $\overline{3}$·1903317.

Electrical Formulæ, by PAGET HIGGS, LL.D., C.E., *and* R. S. BROUGH—*continued*

32. 1 grain = 0·064799 gramme.

log. 0·064799 = $\bar{2}$·8115683.

1 gramme = 15·43235 grains.

log. 15·43235 = 1·1884320.

grms. per yard	×	4·47317 =	lbs. per knot.
„ „ foot	×	13·41951 =	„ „
grains per foot	×	0·8696 =	„ „
ozs. (av.)	×	380 =	„ „
grms. per mètre	×	4·089 =	„ „
„ „ yard	×	5·146 =	grains per foot.
„ „ mètre	×	4·7038 =	„ „
„ „ mètre	×	14·115 =	„ per yard.

kiloms.	×	0·6213824 =	miles	(log. $\bar{1}$·7933573).
miles	×	1·609314 =	kiloms.	(log. 0·2066370).
knots	×	1·85528 =	„	(log. 0·2684141).
kiloms.	×	0·539001 =	knots	(log. $\bar{1}$·7315888).
knots	×	1·15284 =	miles	(log. 0·0617540).
miles	×	0·86742237 =	knots	(log. $\bar{1}$·9382344).
knots	×	2029 =	yards	(log. 3·3072820).
yards	×	0·0004929 =	knots	(log. $\bar{4}$·6927588).
kiloms.	×	1093·633 =	yards	(log. 3·0383585).
yards	×	·0009144 =	kiloms.	(log. $\bar{4}$·9611362).

Copper resistance per knot at 75° F. × ·5214 = resist. per kilom. at 15° C.

C. R. at 15° C. per kilom. × 1·9176 = C. R. at 75° F. per knot.

Electrical Formulæ, by Paget Higgs, LL.D., C.E.—*continued.*

33. Rate of doing work $= \frac{E^2}{R}$ for a galvanic element $= 10^7$ for 1 volt through 1 ohm, or 1 volt-ohm uses $\frac{1}{3000}$ gramme of zinc and does 10^7 absolute units of work per second. 1 HP = 746 volt-ohms, and is equivalent to the consumption of $\frac{746}{3000}$ grammes of zinc per second in a Danieli's cell, or 895·2 grammes per hour.

34. **Potential** at any point of a conducting **series**: Let M N be the conductor length and X an intermediate point. Let m and n be given potentials at M and N, and x potential at X. If r be the resistance between M and X, r_1 between X and N, and R between M and N $= r + r_1$, then $x = \frac{r_1 m + r n}{R}$.

35. When a cable insulated at both ends is charged by a battery, the potential of the charge will be the same at all points of its length, and if the two ends are put simultaneously to earth the charges flowing out of them will be equal; and since the flow is from the middle point of the cable towards the ends, this point will keep its potential a maximum above all other points in the cable length. But with a cable charged with one end to earth, the curve of fall of potential will be a parabola, two-thirds of the charge returning to the charging end.

36. When a cable whose farther end is to earth is charged by a battery whose resistance is small

Electrical Formulæ, by PAGET HIGGS, LL.D., C.E.—*continued.*

compared with the resistance of the conductor of the cable, the charge it will take will be directly proportional to its length. If the resistance of the battery is large compared with that of the conductor, the charge the cable will take will be directly proportional to the square of its length. When two or more cables whose farther ends are to earth are charged so that the strengths of the currents flowing through them are the same, the charges will be directly proportional to the squares of the lengths.

37. If $d\,x$ = thickness of differential cylinder at distance x from longitudinal axis of cable, its resistance will be $d\,r = \frac{d\,x}{2\,\pi\,l\,x\,\lambda}$, and the whole resistance of length l =

$$\frac{1}{2\,\pi\,l\,\lambda}\int_r^R \frac{d\,x}{x} = \frac{\log._\epsilon \frac{R}{r}}{2\,\pi\,l\,\lambda},$$

λ being the specific conductivity.

38. The resistance to the flow of electricity from a central electrode of radius ρ to the periphery of a regular polygon of n sides is

$$\frac{1}{2\,\pi\,k\,\delta}\left(\log.\frac{r}{\rho}\cdot\frac{4}{3+\cos.\frac{\pi}{n}}\right);$$

Electrical Formulæ, by PAGET HIGGS, LL.D., C.E.—*continued.*

r being the radius of the inscribed circle, δ the thickness of the plate.

39. Percentage loss of current: Let k = total conductor resistance; g = total insulating resistance, S = current sent, and R = current received;

$$R = \frac{2\,S}{e^{\sqrt{\frac{k}{g}}} + e^{-\sqrt{\frac{k}{g}}}}$$

which gives a result independent of the length of the cable, and only dependent on the ratio of the total resistances of conductor and dielectric. The percentage of loss is

$$P = 100\,(1 - R) = 100\left(1 - \frac{2\,S}{e^{\sqrt{\frac{k}{g}}} + e^{-\sqrt{\frac{k}{g}}}}\right).$$

40. In the case of a wire excentrically placed, the electrostatic capacity =

$$\frac{I}{2\log._{\epsilon}\dfrac{R^2 - f^2}{R\,R'}},$$

I being the specific inductive capacity, R = inner radius of conducting sheath, R′ radius of wire (of

Electrical Formulæ, by PAGET HIGGS, LL.D., C.E.—*continued.*

which R must be a considerable multiple), f = distance between axes of R′ and R, where

$$\frac{I}{2 \log. \frac{R}{R'}}$$

is usual concentric form.

41. To reduce current flowing through galvanometer to its $\frac{1}{n}$th part, insert a shunt whose resistance is $\frac{1}{n-1}$th part of g. The compensating resistance will be $g\frac{n-1}{n} = \frac{g^2}{g+s}$.

42. Correction for readings on mirror galv.:

$$s_1 : s_2 :: d_2(\sqrt{z^2 + d^2_1} - z) : d_1(\sqrt{z^2 + d^2_2} - z)$$

d = deflection; z = distance of mirror from scale in divisions of scale.

43. The log. of $\frac{\text{amplitude of a vibration}}{\text{that next following}} = \lambda =$ logarithmic decrement. If C_1 is amplitude of 1st and C_n that of nth vibration, then

$$\lambda = \frac{1}{n-1} \log._\epsilon \left(\frac{C_1}{C}\right).$$

Electrical Formulæ, by PAGET HIGGS, LL.D., C.E.—*continued.*

44. Tension spark in air:

Distance. Centimètre.	Electrostatic Units = a.
·0086	2·30
·0127	3·26
·0190	4·26
·0281	5·64
·0408	6·18
·0563	8·11
·0584	8·15
·0688	9·69
·0904	12·20
·1056	13·95
·1325	17·36

(*Thomson*). $\dfrac{a}{\cdot 000374}$ = Daniell's elements.

45. Measurement of short intervals of time: By discharge of condenser: f = capacity of condenser in microfarads; R = its insulation resistance: P = potential before, p = potential after time t (seconds),

$$t = \frac{f \log._{\epsilon} \dfrac{P}{p}}{\dfrac{R + r}{R\, r}},$$

where r is resistance inserted between condenser-terminals in fraction of megohms. If R be infinite to r, then $t = r f \log._{\epsilon} \dfrac{P}{p}$.

By fall of charge on electrometer: P and p are the electrometer readings before and after the time t.

By taking r small, very minute intervals of

Electrical Formulæ, by Paget Higgs, LL.D., C.E.—*continued.*

time may be more accurately measured than by any mechanical chronograph, it being arranged that during the time t the condenser is made to discharge through r, its potentials (P) before and after (p) being measured in the ordinary manner.

46. *Table of Resistances at* 0° C. (Jenkin.)

	Wire, 1 ft. Weighing 1 grain.	One mètre weighing 1 gramme	One foot by ·001″ diameter.	One mètre by 1 mm. diameter.
Silver, annealed ..	0·2214	0·1544	9·936	0·01937
„ hard drawn	0·2421	0·1689	9·151	0·02103
Copper, annealed ..	0·2064	0·1440	9·718	0·02057
„ hard drawn	0·2106	0·1469	9·940	0·02104
Gold, annealed ..	0·5849	0·4080	12·52	0·02650
„ hard drawn ..	0·5950	0·4150	12·74	0·02697
Aluminium, annealed	0·0682	0·0576	17·72	0·03751
Zinc, pressed	0·5710	0·3983	32·22	0·07244
Platinum, annealed	3·536	2·464	55·09	0·1166
Iron, annealed ..	1·2425	0·7522	59·40	0·1251
Nickel, annealed ..	1·0785	0·8666	75·78	0·1604
Tin, pressed	1·317	0·9184	80·36	0·1701
Lead, pressed ..	3·236	2·257	119·39	0·2527
Antimony, pressed	3·324	2·3295	216·0	0·4571
Bismuth, pressed ..	5·054	3·525	798·0	1·689
Mercury, liquid ..	18·740	13·071	600·0	1·270
Platinum-silver (usual alloy)	4·243	2·959	143·35	0·3140
German silver ..	2·652	1·850	127·32	0·2695

The resistance of silver varies about 0·377 per cent. for 1° C. at 20° C., of copper 0·388 per cent., of mercury ·072 per cent., of platinum-silver ·031 per cent., and of German silver ·044 per cent.

Electrical Formulæ, by PAGET HIGGS, LL.D., C.E., *and* R. S. BROUGH—*continued.*

TABLE for converting the resistance of COPPER WIRE measured at 80° F. to the corresponding resistance, at any temperature between 60° and 110° F. This Table can be used for 75° F. as standard by shifting 75 on the temperature column to correspond with 10,000, &c., on the resistance columns.

Temp. F°	10,000	20,000	30,000	40,000	50,000	60,000	70,000	80,000	90,000
60	9618	19237	28855	38474	48092	57711	67329	76948	86566
61	9638	19275	28913	38550	48188	57825	67463	77100	86738
62	9657	19313	28970	38626	48283	57940	67596	77253	86909
63	9676	19351	29027	38703	48378	58054	67739	77406	87081
64	9695	19390	29084	38779	48474	58169	67863	77558	87253
65	9714	19428	29142	38855	48569	58283	67997	77711	87426
66	9733	19466	29199	38932	48665	58398	68130	77863	87596
67	9752	19504	29256	39008	48760	58512	68264	78016	87768
68	9771	19542	29313	39084	48855	58626	68398	78169	87940
69	9790	19580	29370	39161	48951	58741	68531	78321	88111
70	9809	19618	29428	39237	49046	58855	68665	78474	88283
71	9828	19657	29485	39313	49142	58970	68798	78626	88455
72	9847	19695	29542	39390	49237	59084	68932	78779	88626
73	9866	19733	29599	39466	49332	59199	69065	78932	88798
74	9886	19771	29657	39542	49428	59313	69199	79084	88970
75	9905	19809	29714	39618	49523	59428	69332	79237	89141
76	9924	19847	29771	39695	49618	59542	69466	79390	89313
77	9943	19896	29828	39791	49714	59657	69599	79582	89485
78	9962	19924	29886	39847	49809	59771	69733	79695	89657
79	9981	19962	29943	39924	49905	59886	69866	79847	89828
80	10000	20000	30000	40000	50000	60000	70000	80000	90000

Electrical Formulæ, by Paget Higgs, LL.D., C.E., *and* R. S. Brough—*continued.*

Table for converting the resistance of Copper Wire—*continued.*

Temp. F°	10,000	20,000	30,000	40,000	50,000	60,000	70,000	80,000	90,000
81	10019	20038	30057	40076	50095	60114	70134	80153	90172
82	10038	20076	30114	40153	50191	60229	70267	80305	90343
83	10057	20114	30172	40229	50286	60343	70401	80458	90515
84	10076	20153	30229	40305	50382	60458	70534	80610	90687
85	10095	20191	302[illegible]6	40382	50477	60572	70668	80763	90858
86	10114	20229	30343	40458	50572	60687	70801	80916	91030
87	10134	20267	30401	40534	50668	60801	70935	81068	91202
88	10153	20305	30458	40610	50763	60916	71068	81221	91374
89	10172	20343	30515	40687	50858	61030	71202	81374	91545
90	10191	20382	30572	40763	50954	61145	71335	81526	91717
91	10210	20420	30630	40839	51049	61259	71469	816[illegible]	91889
92	10229	20458	30687	40916	51145	61374	71602	81831	92060
93	10248	20496	30744	40992	51240	61488	71736	81984	92232
94	10267	20534	30801	41068	51335	61602	71870	82137	92404
95	10286	20572	30858	41145	51431	61717	72003	82289	92575
96	10305	20610	30916	41221	51526	61831	72137	82442	92747
97	10324	20649	30973	41297	51621	61946	72270	82594	92919
98	10343	20687	31030	41374	51717	62060	72404	82747	93090
99	10362	20725	31087	41450	51812	62175	72537	82900	93262
100	10382	20763	31145	41526	51928	62288	72671	83052	93434
101	10401	20801	31202	41602	52003	62404	72804	83205	93606
102	10420	20839	31259	41679	52098	62518	72938	83358	93777
103	10439	20878	31316	41755	52194	62633	73071	83510	93949
104	10458	20916	31374	41831	52289	62747	73205	83663	94121
105	10477	20954	31431	41908	52385	62862	73338	83815	94292
106	10496	20992	31488	41984	52480	62976	73472	83968	94464
107	10515	21030	31545	42060	52575	63090	73605	84121	94636
108	10534	21068	31602	42137	52671	63205	73739	84273	94807
109	10553	21106	31660	42213	52766	63319	73873	84426	94979
110	10572	21145	31717	42289	52862	63434	74006	84578	95151

Telegraph Construction, by R. S. Brough.

Iron Wire.

B. W. G.	Diameter in inches.	Weight per yard in pounds.	Breaking strain of soft iron wire in pounds.	Ratio of resistance to that of No. 1 wire.
1	0·300	0·6875	4000	1·000
2	0·280	0·5990	3400	1·148
3	0·260	0·5165	2900	1·331
$3\frac{1}{2}$	0·250	0·4800	2700	1·440
4	0·240	0·4400	2500	1·562
5	0·220	0·3700	2200	1·860
$5\frac{1}{2}$	0·210	0·3409	2000	2·041
6	0·200	0·3056	1800	2·250
7	0·185	0·2615	1520	2·630
8	0·170	0·2210	1200	3·114
9	0·155	0·1836	950	3·746
$9\frac{1}{2}$	0·149	0·1704	900	4·054
10	0·140	0·1497	820	4·592
11	0·125	0·1195	650	5·760
12	0·110	0·0924	510	7·438
$12\frac{1}{2}$	0·105	0·0852	450	8·163
13	0·095	0·0705	400	9·972
14	0·085	0·0551	350	12·457
15	0·075	0·0429	300	16·000
16	0·065	0·0322	200	18·367
17	0·057	0·0284	150	21·302

Note.—The resistance per mile of No. 1 wire is about 5 ohms at 80° Fah.

Telegraph Construction, by R. S. BROUGH—*continued.*

DIP OF SOFT IRON WIRE AT QUARTER BREAKING STRAIN.

Span in feet.	Dip in feet.	Span in feet.	Dip in feet.
225	1·33	1575	71·62
240	1·64	1650	79·00
264	1·98	1725	86·52
300	2·56	1800	94·41
330	3·10	1875	102·67
375	4·00	1950	111·31
450	5·76	2025	120·33
525	7·85	2100	129·81
600	10·26	2175	139·56
675	13·00	2250	149·78
750	16·05	2325	160·40
825	19·44	2400	171·43
900	23·15	2475	182·95
975	27·20	2550	194·80
1050	31·59	2625	207·13
1125	36·31	2700	219·50
1200	41·36	2775	233·20
1275	46·76	2850	247·00
1350	52·51	2925	261·20
1425	58·60	3000	276·00
1500	65·04		

GILBERT'S TABLE—(Ordinary Catenary).

$x = 100 =$ half span.

c = modulus.	d = dip.	s = length of wire.	l = ordinate at insulator.	90°—i°.		
				°	′	″
2000	2·500511	100·041474	2002·500511	87	8	11
1950	2·564593	100·042440	1952·564593	87	3	46
1900	2·632163	100·045727	1902·632163	86	59	8
1850	2·703298	100·047540	1852·703298	86	54	15
1800	2·778421	100·050163	1802·778421	86	49	6
1750	2·857914	100·054318	1752·857914	86	43	40
1700	2·942018	100·057566	1702·942018	86	37	53
1650	3·031204	100·060788	1653·031204	86	31	46
1600	3·125974	100·064421	1603·125974	86	25	16
1550	3·226852	100·068245	1553·226852	86	18	21
1500	3·334558	100·073939	1503·334558	86	10	59
1450	3·449618	100·078929	1453·449618	86	3	6
1400	3·572907	100·084490	1403·572907	85	54	39
1350	3·705344	100·090750	1353·705344	85	45	35
1300	3·847958	100·097440	1303·847958	85	35	45
1250	4·002035	100·105463	1254·002035	85	25	16
1200	4·168981	100·114680	1204·168981	85	13	51
1150	4·350543	100·125801	1154·350543	85	1	26
1100	4·548545	100·137346	1104·548545	84	47	54
1050	4·765440	100·150553	1054·765440	84	33	5
1000	5·004084	100·165906	1005·004084	84	16	48
980	5·106408	100·173025	985·106408	84	9	49

Ordinary Catenary—*continued.*

c = modulus.	d = dip.	s = length of wire.	l=ordinate at insulator.	90°—i°. °	′	″
960	5·213007	100·180582	965·213007	84	2	13
940	5·324098	100·188974	945·324098	83	54	58
920	5·440045	100·196191	925·440045	83	47	4
900	5·561266	100·205825	905·561266	83	38	48
880	5·687876	100·214837	885·687876	83	30	11
860	5·820479	100·225255	865·820479	83	21	9
840	5·959364	100·235949	845·959364	83	11	42
820	6·105033	100·247321	826·105033	83	1	47
800	6·258102	100·260296	806·258102	82	51	23
780	6·418938	100·273356	786·418938	82	40	28
760	6·588360	100·288153	766·588360	82	28	57
740	6·767004	100·304328	746·767004	82	16	50
720	6·955577	100·321527	726·955577	82	4	3
700	7·154926	100·339869	707·154926	81	50	33
680	7·366193	100·360765	687·366193	81	36	15
660	7·590181	100·382517	667·590181	81	21	6
640	7·828368	100·407143	647·828368	81	5	1
620	8·081923	100·433570	628·081923	80	47	54
600	8·352608	100·463404	608·352608	80	29	40
580	8·642033	100·495985	588·642033	80	10	11
560	8·952299	100·532176	568·952299	79	49	27
540	9·283888	100·562366	549·283888	79	27	2
520	9·645021	100·617335	529·645021	79	2	56
500	10·033315	100·667683	510·033315	78	36	59
480	10·454508	100·725490	490·454508	78	8	55

ORDINARY CATENARY—*continued.*

c = modulus.	d = dip.	s = length of wire.	l=ordinate at insulator.	$90°-i°$.		
				°	′	″
460	10·912412	100·789382	470·912412	77	38	28
440	11·412622	100·863052	451·412622	77	5	23
420	11·961025	100·947150	431·961025	76	29	6
400	12·565207	101·044792	412·565207	75	49	22
380	13·233994	101·158163	393·233994	75	5	35
360	13·978365	101·290757	373·978365	74	17	7
340	14·812141	101·447796	354·812141	73	32	10
320	15·752501	101·635337	335·752501	72	22	46
300	16·821529	101·862069	316·821529	71	14	44
280	18·047685	102·139232	298·047685	69	57	31
260	19·468993	102·483745	279·468993	68	29	13
240	21·126437	102·893226	261·126437	66	47	38
220	23·118850	103·473548	243·118850	64	48	38
200	25·525175	104·219022	225·525175	62	28	34
180	28·559946	105·343499	208·559946	59	39	43
160	32·280531	106·638654	192·280531	56	19	0
140	37·258541	108·722538	177·258541	52	10	2
120	44·134402	111·982596	164·134402	46	58	48
100	54·308027	117·520071	154·308027	40	23	42
95	57·674415	119·517684	152·674415	38	28	45
90	61·511583	121·884206	151·511583	36	26	34
85	65·852160	124·624934	150·852160	34	17	44
80	71·073875	128·153485	151·073875	31	58	28
75	77·147407	132·377616	152·147407	29	32	4
70	84·433443	137·657866	154·433443	26	57	10

Telegraph Construction, by PAGET HIGGS, LL.D., C.E.

Table for calculating Inner and Outer Diameter of Iron Sheathing.

Rule: Multiply diameter of wire by constant corresponding to number of wires. The diameter of wire may be in mils, inches, or millimètres. To use this table for outer diameter of strand, take the number of wires around the central for entry. The inner diameter is obtained from the outer diameter by subtracting 2.

No. of Wires.	Outside Diameter.	Log.	No. of Wires.	Outside Diameter.	Log.
3	2·155	0·33345	17	6·442	0·80889
4	2·414	0·38274	18	6·759	0·82988
5	2·701	0·43152	19	7·075	0·84973
6	3·000	0·47712	20	7·392	0·86876
7	3·305	0·51917	21	7·709	0·88672
8	3·613	0·55787	22	8·027	0·90455
9	3·924	0·59373	23	8·344	0·92137
10	4·236	0·62696	24	8·661	0·93757
11	4·549	0·65792	25	8·979	0·95323
12	4·864	0·68699	26	9·296	0·96830
13	5·179	0·71425	27	9·614	0·98290
14	5·494	0·73989	28	9·931	0·99699
15	5·810	0·76418	29	10·249	1·01072
16	6·126	0·78718	30	10·567	1·02407

Telegraph Construction, by PAGET HIGGS, LL.D., C.E.

Table for Calculating Hemp and Asphalte Areas and Weights.

Table A.			Table B.	
Area of section inside Iron Sheathing = $d^2 \times a$ where d is diam. of single wire.			Areas for Asphalte Casings.	
No.	a.	Log.	k.	Log.
3	0·04031	$\bar{2}$·6054128	2·396505	0·3795783
4	0·21460	$\bar{1}$·3316297	3·356194	0·5258470
5	0·54238	$\bar{1}$·7343037	4·469373	0·6502466
6	1·02728	0·0116888	5·739672	0·7588870
7	1·67041	0·2228231	7·168203	0·8554103
8	2·47223	0·3930889	8·755420	0·9422770
9	3·43292	0·5356637	10·501509	1·0212518
10	4·55262	0·6582614	12·406598	1·0936527
11	5·83135	0·7657691	14·470727	1·1604903
12	7·26916	0·8614860	16·693936	1·2225587
13	8·86608	0·9477316	19·076255	1·2804931
14	10·62211	1·0262108	21·617684	1·3348092
15	12·53727	1·0982029	24·318243	1·3859322
16	14·61157	1·1646969	27·177942	1·4342166
17	16·84500	1·2264710	30·196771	1·4799605
18	19·23759	1·2841506	33·374750	1·5234180
19	21·78931	1·3382435	36·711869	1·5648064
20	24·50018	1·3891693	40·208138	1·6043140
21	27·37019	1·4372778	43·863537	1·6421037
22	30·39935	1·4828643	47·678106	1·6783189
23	33·58768	1·5261799	51·651835	1·7130857
24	36·93514	1·5674398	55·784694	1·7465151
25	40·44176	1·6068310	60·076713	1·7787060
26	44·10753	1·6445127	64·527882	1·8097474
27	47·93245	1·6806297	69·138201	1·8397181
28	51·91656	1·7153059	73·907700	1·8686897
29	56·05978	1·7486514	78·836319	1·8967264
30	60·36216	1·7807647	83·024098	1·9238867

Telegraph Construction, by PAGET HIGGS, LL.D., C.E. *—continued.*

Single Sheathing: $d^2 \times \cdot 7854 \times kn$ (Table A) less $D^2 \times \cdot 7854$, where d is diameter single iron wire and D is diameter of core, n number of wires.

Double Sheathing: $\left\{ d^2 \times \overset{\text{(Outside.)}}{\cdot 7854} \times kn \right\}$ (Table A) less $\left\{ d'^2 \times \overset{\text{(Inside.)}}{\cdot 7854} \times kn \right\}$ (Table B). Then as 1 cwt. of Ital. or Russ. hemp = 4928 cub. in., tarred hemp = 3472 cub. in., and as there are 73044 cub. in. in a knot length of 1″ sectional area $\left(\frac{73044}{4928} = 14 \cdot 822, \text{\&c.}\right)$.

Area of hemp section in inches $\times\ 14 \cdot 822$ = cwts. Ital. hemp per knot.
„ $\times\ 21 \cdot 038$ = tarred hemp per knot.
„ $\times\ 15 \cdot 528$ = Manilla hemp per knot.

Area in square mm. $\times \cdot 0230$ = cwts. Ital. hemp per knot.
„ $\times \cdot 326$ = cwts. tarred hemp per knot.
„ $\times \cdot 0241$ = cwts. Manilla hemp per knot.

Asphalte casing (outer diam.) $^2 \times \cdot 7854$ less $d^2\ kn$ (Table B) gives area.

And this in sq. in. $\times\ 36$ = cwts. asphalte per knot.
„ mm. $\times \cdot 0558$ = cwts. asphalte per knot.
„ mm. $\times\ 3 \cdot 3928$ = kilos. per knot.

Area in sq. mm. $\times\ 1 \cdot 1685$ = kilos. Ital. hemp.
„ $\times\ 1 \cdot 6561$ = „ tarred „
„ $\times\ 1 \cdot 2243$ = „ Manilla „

Telegraph Construction, by PAGET HIGGS, LL.D., C.E.—*continued.*

Ratios of Weights and Diameters: g. p. wires.

$\frac{W}{w}$	$\frac{D}{d}$	Log. $\frac{D}{d}$	$\frac{W}{w}$	$\frac{D}{d}$	Log. $\frac{D}{d}$	$\frac{W}{w}$	$\frac{D}{d}$	Log. $\frac{D}{d}$
0·75	2·78	0·44404	1·04	3·21	0·50651	1·33	3·60	0·55630
0·76	2·79	0·44560	1·05	3·22	0·50786	1·34	3·61	0·55751
0·77	2·81	0·44871	1·06	3·23	0·50920	1·35	3·63	0·55991
0·78	2·82	0·45025	1·07	3·24	0·51055	1·36	3·64	0·56110
0·79	2·84	0·45332	1·08	3·26	0·51332	1·37	3·64	0·56110
0·80	2·85	0·45484	1·09	3·27	0·51455	1·38	3·65	0·56229
0·81	2·87	0·45788	1·10	3·29	0·51720	1·39	3·67	0·56467
0·82	2·89	0·46090	1·11	3·30	0·51851	1·40	3·68	0·56585
0·83	2·90	0·46240	1·12	3·31	0·51983	1·41	3·69	0·56703
0·84	2·92	0·46538	1·13	3·32	0·52244	1·42	3·71	0·56937
0·85	2·93	0·46687	1·14	3·34	0·52375	1·43	3·72	0·57054
0·86	2·95	0·46982	1·15	3·35	0·52504	1·44	3·73	0·57171
0·87	2·96	0·47129	1·16	3·36	0·52634	1·45	3·75	0·57403
0·88	2·98	0·47432	1·17	3·38	0·52892	1·46	3·76	0·57519
0·89	2·99	0·47567	1·18	3·39	0·53020	1·47	3·77	0·57634
0·90	3·01	0·47857	1·19	3·40	0·53148	1·48	3·78	0·57749
0·91	3·02	0·48001	1·20	3·42	0·53403	1·49	3·80	0·57978
0·92	3·04	0·48287	1·21	3·43	0·53529	1·50	3·81	0·58092
0·93	3·05	0·48430	1·22	3·44	0·53656	1·51	3·82	0·58206
0·94	3·07	0·48714	1·23	3·46	0·53908	1·52	3·84	0·58433
0·95	3·08	0·48885	1·24	3·47	0·54033	1·53	3·85	0·58546
0·96	3·10	0·49136	1·25	3·49	0·54283	1·54	3·86	0·58659
0·97	3·11	0·49276	1·26	3·50	0·54407	1·55	3·87	0·58771
0·98	3·12	0·49415	1·27	3·52	0·54654	1·56	3·88	0·58883
0·99	3·14	0·49693	1·28	3·53	0·54777	1·57	3·89	0·58995
1·00	3·15	0·49831	1·29	3·54	0·54900	1·58	3·90	0·59106
1·01	3·16	0·49969	1·30	3·55	0·55020	1·59	3·91	0·59218
1·02	3·18	0·50243	1·31	3·57	0·55267	1·60	3·92	0·59329
1·03	3·19	0·50379	1·32	3·58	0·55388			

These logs. are to be increased by the following logs. for the several strands,

viz.: 3 strand 0·03342
7 strand 0·00119

Telegraph Construction, *by* PAGET HIGGS, LL.D., C.E.—*continued.*

Multipliers for regular polygons.

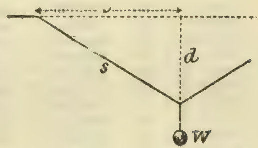
Diameter of circumscribing circle, the side being = 1. Subtract unity from tabulated numbers for outside diameters.

Areas of regular polygons,

S = length of side. $S^2 \times k$ = area.

No. of sides.	k	Log.	No. of sides.	k	Log.
3	0·43301	$\bar{1}$·6364979	17	22·73549	1·3567043
4	1·00000	0·0000000	18	25·52077	1·4068938
5	1·72048	0·2356496	19	28·46519	1·4543141
6	2·59808	0·4146525	20	31·56876	1·4992575
7	3·63391	0·5610907	21	34·831[illegible]7	1·5419718
8	4·82843	0·6838057	22	38·25333	1·5826692
9	6·18182	0·7911164	23	41·83436	1·6215331
10	7·69421	0·8861641	24	45·57452	1·6587221
11	9·36564	0·9715374	25	49·47284	1·6943756
12	11·19615	1·0490687	26	53·53231	1·7286160
13	13·18577	1·1201055	27	57·74993	1·7615516
14	15·33450	1·1856696	28	62·12673	1·7932785
15	17·64236	1·2465567	29	66·66265	1·8238826
16	20·10936	1·3033983	30	71·35773	1·8534410

Formulæ for Strain when laying Submarine Cable, with ordinary dynamometer, by J. R. BRITTLE, C.E.



W = weight of movable pulley.
d = depression below horizontal line.
l = length between bearing wheel and movable wheel measured horizontally.
s = strain on cable.

$$s = \frac{W\,l}{2\,d} \text{ approximately for small values of } d.$$

Or, $d = \dfrac{W\,l}{2\,s}$.

More exactly $d = \dfrac{W\,l}{\sqrt{4\,s^2 - W^2}}$.

STRAINS ON TELEGRAPH WIRE. (Indian Telegraph Dept.)

Applicable to Indian Wire Specification of 1872.

Wires made on this specification have been used in Japan, New Zealand, Australia, Cape, and South America.

Constant strength of iron wire = 6000 yards of itself.

" " steel " = 18000 " "

With a dip of 30 inches per 100 yards span the constant working strain at the insulator = 1500 yards, or approximately $\frac{5}{6}$ths of its weight per mile.

The strain varies directly in proportion to the dip.

WITH THE POINTS OF SUPPORT AT THE SAME LEVEL.

S = Span, or length between supports.
D = Dip of the wire.
L = Length of the curve between supports.
T = Strain at the insulator.
t = Strain at the lowest point of the curve.
w = Weight of a unit of wire.

$$L = S + \frac{8\,D^2}{3\,S}.$$

$$t = \left(\frac{S^2}{8\,D} + \frac{D}{6}\right) w.$$

$$T = \left(\frac{S^2}{8\,D} + \frac{7\,D}{6}\right) w.$$

$$\frac{T}{w} = \left(\frac{S^2}{8\,D} + \frac{7\,D}{6}\right) = \text{working strain of wire.}$$

$$D = \frac{1}{7}\left(\frac{3\,T}{w} - \frac{\sqrt{36\,\frac{T^2}{w^2} - 21\,S^2}}{2}\right).$$

WITH SUPPORTS AT UNEQUAL LEVELS.

x = Horizontal distance from the lowest point of the curve to the lower support.
y = Ditto ditto to the higher support.
a = Difference in level of supports,

Strains on Telegraph Wire.

WITH SUPPORTS AT UNEQUAL LEVELS—*continued.*

p = The parameter.

$$= \frac{2\,T}{w}.$$

$$x = \frac{S^2 - a\,p}{2\,S}.$$

$$y = \frac{S^2 + a\,p}{2\,S}.$$

TO FIND THE FACTORS OF THE BACK SPAN.

S = Length of main span in yards.
s = „ back „
d = Dip of back span in feet.
n = Proportion of weight per mile of back span wire to that of main span wire.
r = Proportion of dip in feet per 100 yards at which the main span wire is calculated.

$$s = 50\sqrt{\frac{d}{n\,r}}.$$

WIND PRESSURE.

f = Pressure of wind in lbs. per square foot.
W = Weight of wire in lbs. per mile.
L = Length of curve in feet.
F = Total pressure of wind on any length L in lbs.
b = Diameter of wire in inches.

$$F = \frac{f\,L}{2117 \cdot 16}\sqrt{W} = \frac{f\,L\,b}{18}.$$

STRAIN ON STAYS.

T = Strain on the insulator.
θ = Angle the stay makes with the ground.

$$\text{Strain on the stay} = \frac{T}{\cos.\theta}.$$

Relative Speed of Working Cables of similar Length.
(Sir W. Thompson.)

D = Diameter of insulator.
d = " conductor.

$$S = \text{Relative speed} = 200\,\epsilon \left(\frac{d}{D}\right)^2 \log._\epsilon \frac{D}{d}.$$

$\frac{d}{D}$	$\frac{D}{d}$	S	$\frac{d}{D}$	$\frac{D}{d}$	S	$\frac{d}{D}$	$\frac{D}{d}$	S
0·1	10	·1252	0·5	2·	·9421	0·8	1·25	·7764
0·2	5	·3500	0·6	1·66	·9996	0·9	1·11	·4684
0·3	3·33	·5891	0·6065	1·649	1·0000			
0·4	2·5	·7971	0·7	1·429	·9554			

Actual Speed of Working in Cables.

L = Length in knots. S = Speed words per minute.

Red Sea, L = 629, S = 11; Alexandria, Malta, L = 925, S = 19; Persian Gulf, L = 1000, S = 9½; Atlantic (1865), L = 1896, S = 17; Atlantic (1866), L = 1857, S = 17; French Atlantic, L = 2584, S = 15.

Lightning Rod Conference, 1881.

Abstract of Rules.

Points.—Upper terminal should not be sharper than a cone of which the height equals the base, but a foot lower down a copper ring should be screwed and soldered on the upper terminal, on which ring should be fixed 3 or 4 sharp copper needles 6 inches long, ¼ inch diameter at base, platinized gilded, or nickel plated.

Upper Terminals.—Number to depend on the size of the building, material, configuration, and height of the several parts. Even short chimney-stacks when exposed must be protected by short terminals connected to the nearest rod.

Fixing.—It is preferable to take the rods down the side of the building most exposed to rain. The holdfasts should hold firmly, but should not pinch the rod or prevent expansion and contraction.

Factory Chimneys.—Should have a copper band round the top, with stout sharp copper points about 1 foot long at intervals of 2 or 3 feet; the points should be protected from oxidation.

Ornamental Ironwork.—Finials and ridges to be connected with the conductor. An independent upper terminal is desirable.

LIGHTNING CONDUCTORS—*continued.*

Material for Rod.—Copper not less than 6 ounces per foot run, of conductivity not less than 90 per cent. pure copper, either in the form of tape or rope of wire not less than 12 B.W.G. Iron may be used not less than $2\frac{1}{4}$ lbs. per foot run.

Joints.—Well cleaned, in addition to being screwed, or scarfed, or riveted, must be thoroughly soldered.

Protection.—Copper rods for 10 feet above and some distance below ground to be enclosed in an iron pipe.

Painting.—Iron rods, whether galvanized or not, should be painted. Copper may be painted or not as desired.

Curvature.—The rod should not be bent abruptly. In no case should the length of the rod between two points be more than half as long again as the straight line joining them. When a string course will allow it, the rod may be carried through, instead of round, the projection, the hole being large enough to allow expansion and contraction.

Extensive Masses of Metal.—The conductor should be connected with large masses of metal, such as hot-water pipes, but should be kept away from all soft metal pipes and from internal gas-pipes of every kind. Church bells in well-protected spires need not be connected.

Earth Connection.—The lower extremity of the conductor must be buried in permanently damp soil. Proximity to rain-pipes and drains is desirable. Bifurcation of the conductor below the surface is desirable. A strip of copper tape may be led to the nearest gas or water *main* (not a lead pipe) and soldered to it; or the tape may be soldered to a sheet of copper 3 feet $\times$ 3 feet $\times$ $\frac{1}{16}$ inch thick, buried in permanently wet earth and surrounded by cinders or coke; or many yards of the tape with surface not less than 18 square feet may be laid in a trench surrounded by coke. When iron is used, a galvanized iron plate of similar dimensions should be used.

Inspection.—The conductor should be examined and tested by a duly qualified person.

Collieries.—Head gear of collieries should be protected by proper lightning conductors.

ICE AND SNOW.

Ice. At 32° Fahr., 1 cubic inch = ·0334 lb.; 1 cubic foot = 57·8 lbs. 1 lb = 29·94 cubic ins. = ·0174 cubic ft. Specific gravity = ·926.* Specific heat ·504.

Snow. 1 cubic inch = ·003 lb.; 1 cubic foot = 5·2 lbs. 1 lb. = 332·3 cubic ins. = ·1923 cubic ft. Specific gravity ·0833. Snowfall = ·433 lb. per inch depth per super. foot.

* De Mairan; if from water purged from air, sp. gr. = ·954.

Expansion of Gases.

Boyle's (Mariotte's) Law.

"The density of a gas is proportional to its pressure for the same temperature." Saturated steam is not a perfect gas.

Perfect gases have as nearly as possible the same coefficient of expansion under all temperatures.

P = Pressure at zero = 760 millimètres, or 29·92 inches of mercury,
t = Temperature of gas.
V = Volume of gas at zero.
v = " " at any temperature t.
W = Weight " at zero.
w = " " at any temperature t.
p = Pressure at any temperature t.
K = Coefficient of expansion with each degree of temperature = ·003665 Centigrade = ·002036 Fahr.

$$p = P(1 + Kt).$$

$$V = \frac{v}{1 + Kt}. \qquad v = V(1 + Kt).$$

$$W = w(1 + Kt). \qquad w = \frac{W}{1 + Kt}.$$

Balloons.

W = Weight to be raised, including the weight of the balloon itself.
A = Weight of a cubic foot of air.
G = " " the gas.
D = Diameter of the balloon.

$$D = \sqrt[3]{\frac{W}{\cdot 5236\,(A - G)}}.$$

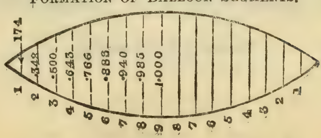
$$W = \cdot 5236\, D^3 (A - G).$$

Approximately with hydrogen gas, but varying with the state of the atmosphere,

$$D = \sqrt{25 \cdot 5\, W}. \qquad W = \cdot 0392\, D^3.$$

The buoyancy of hydrogen is about 13·3 feet to a lb.

Formation of Balloon Segments.



Electric Lighting.

APPROXIMATE RULE FOR FUSIBLE SAFETY CATCHES OF LEAD.

c = Number of ampères in the current.
d = Diameter of safety catch in centimeters.

$$c = \sqrt{38000\, d^3} \quad d = \sqrt[3]{\frac{c^2}{38000}}.$$

The length of the safety catch should not be less than 300 d.

GRAMME ARC-LIGHTS.

	M	A G	C T	C Q	D Q
Number of carcels, mean	226	490	1015	1241	2198
Revolutions per minute ..	1600	820	675	380	495
Length of arc, *mm*... ..	3	4	4	4·5	6
Current, ampères	13·5	24·5	48	65	70
Diameter of carbons, *mm*.	9	13	18	18	20
Carcels projected	625	1200	2500	3300	6000
Horse-power absorbed ..	·93	2·69	5·14	7·94	9·99
Weight of machine, *kgs*...	73	185	390	390	1000
ARMATURE—					
Diameter of wires, *mm*. ..	1·2	1·8	2·8	3·65	4·3
Current through wires ..	6·75	12·25	24	32·5	35
Current per mm^2.	6	4·8	3·9	3·1	2·4
FIELD MAGNETS—					
Diameter of wire, *mm*. ..	1·8	3·4	3·4	3·4	3·8
Current per mm^2.	2·6	1·3	5·3	7·2	1·6

M, used for steam launches; A G, for despatch boats; C T, for ironclads; C Q and D Q, for coast defence.

ELECTRIC LIGHTING—*continued*.

ELECTRIC CANDLES. (Jablochkoff.)

One indicated Horse-power per light—Mean intensity = 41 carcels—Maximum intensity = 45 carcels—Current, $8\frac{1}{2}$ Ampères—Difference of potential at candle, $42\frac{1}{2}$ volts—Electric energy expended, from ·45 to ·50 horse-power,

INCANDESCENT LAMPS. (Siemens).

Normal candles ..	12	16	45
Volts	100	100	100
Ampères	·41	·55	·8
Ohms (Hot.)	244	182	125
Watts	40·5	55	80
Normal candles per electrical horse-power in the lamp	213	209	224

MEASUREMENT OF LIGHT.

1 Carcel lamp, burning 42 grammes of pure Colza oil per hour.

" " = 9·5 English candles = 7·6 German candles.

1 English candle, burning 120 grains of spermaceti per hour.

" " = ·105 carcels.

1 German candle = ·132 carcels.

1 cubic foot of gas per hour, at the following sp. gravities:—

Specific gravity of gas	·4	·5	·6	·7
Equivalent in carcels	1·26	2·1	2·73	3·36

(*See Supplement, Electric Lighting.*)

GAS-WORKS.

Each lamp consumes 5 cubic feet per hour.

	cub. ft. per month.
In winter each lamp consumes from	1800 to 2500
In summer " "	1000 " 1800

	cub. ft. per year.
Average consumption for each lamp =	21,000
Private burners, average about	5,000

Internal lights require 4 cubic feet of gas per hour, and external lights about 5 cubic feet per hour. Where large or Argand burners are used, from 6 to 10 cubic feet will be required.

The pressure with which gas is forced through pipes should seldom exceed $2\frac{1}{2}$ inches of water at the works, or the leakage will exceed the advantages to be obtained from increased pressure.

It is usual to place a governor at every 30 feet change of level.

When pipes are laid at an inclination either above or below the horizon, a correction will have to be made in estimating the supply, by adding or deducting $\frac{1}{100}$ of an inch from the initial pressure for every foot of rise or fall in the length of the pipe.

A retort produces about 600 cube feet of gas in 5 hours with a charge of about $1\frac{1}{2}$ cwt. of coal, or 2800 cube feet in 24 hours.

In estimating the number of retorts required, $\frac{1}{4}$th should be added for being under repairs, &c.

GAS-WORKS—*continued*.

PURIFIERS.

Wet purifiers require 1 bushel of lime mixed with 48 bushels of water for 10,000 cube feet of gas.

Dry purifiers require 1 bushel of lime to 10,000 cubic feet of gas, and 1 superficial foot for every 400 cube feet of gas.

PRODUCTS OF COALS.

Products.	Newcastle. from	Newcastle. to	Cannel. from	Cannel. to
Cube feet of gas per ton of coal	9,500	10,000	11,500	15,000
Lbs. of coke	1,500	1,540	715	720
Lbs. of tar	70	90	710	720
Lbs. of ammoniacal liquor ..	80	120	—	—

Fuel required for retorts, about 20 lbs. per cwt.

MOTION OF GAS IN PIPES.

Q = Quantity of gas in cube feet per hour.
L = Length of pipe in yards.
D = Diameter of pipe in inches.
H = Head of water-pressure in inches.
G = Specific gravity of gas.

$$Q = 1000 \sqrt{\frac{D^5 H}{G L}}.$$

$$D = \cdot 063 \sqrt[5]{\frac{Q^2 G L}{H}}.$$

G may be assumed = ·45 for ordinary calculations.
H " = $\frac{1}{2}$ an inch to 1 inch.

SERVICES FOR LAMPS.

2	lamps	40	feet from main	require	$\frac{3}{8}$	bore of pipe.
4	"	40	"	"	$\frac{1}{2}$	"
6	"	50	"	"	$\frac{5}{8}$	"
10	"	100	"	"	$\frac{3}{4}$	"
15	"	130	"	"	1	"
20	"	150	"	"	$1\frac{1}{4}$	"
25	"	180	"	"	$1\frac{1}{2}$	"
30	"	200	"	"	$1\frac{3}{4}$	"

TABLES OF THE MAXIMUM SUPPLY OF GAS THROUGH PIPES IN CUBIC FEET PER HOUR, THE SPECIFIC GRAVITY BEING TAKEN = ·45, CALCULATED FROM THE FORMULA

$$Q = 1000 \sqrt{\frac{D^5 H}{G L}}. \quad \text{(J. T. Hurst.)}$$

Length of Pipe = 10 yards.

Diameter of Pipe in inches.	Supply of Gas in cube feet per hour.									
	Pressure by the Water-Gauge in inches.									
	·1	·2	·3	·4	·5	·6	·7	·8	·9	1·0
3/8	13	18	22	26	29	31	34	36	38	41
1/2	26	37	46	53	59	64	70	74	79	83
3/4	73	103	126	145	162	187	192	205	218	230
1	149	211	258	298	333	365	394	422	447	471
1¼	260	368	451	521	582	638	689	737	781	823
1½	411	581	711	821	918	1006	1082	1162	1232	1299
2	843	1192	1460	1686	1886	2066	2231	2385	2530	2667

Length of Pipe = 100 yards.

Diameter of Pipe in inches.	Supply of Gas in cube feet per hour.										
	Pressure by the Water-Gauge in inches.										
	·1	·2	·3	·4	·5	·75	1·0	1·25	1·5	2	2·5
1/2	8	12	14	17	19	23	26	29	32	36	42
3/4	23	32	42	46	51	63	73	81	89	103	115
1	47	67	82	94	105	129	149	167	183	211	236
1¼	82	116	143	165	184	225	260	291	319	368	412
1½	130	184	225	260	290	356	411	459	503	581	649
2	267	377	462	533	596	730	843	943	1033	1193	1333
2½	466	659	807	932	1042	1276	1473	1647	1804	2083	2329
3	735	1039	1270	1470	1643	2012	2323	2598	2846	3286	3674
3½	1080	1528	1871	2161	2416	2958	3416	3820	4184	4831	5402
4	1508	2133	2613	3017	3373	4131	4770	5333	5842	6746	7542

GAS-WORKS—*continued.*

Length of Pipe = 1000 yards. (J. T. Hurst.)

Diameter of Pipe in inches.	Supply of Gas in cube feet per hour. Pressure by the Water-Gauge in inches.						
	·5	·75	1·0	1·5	2·0	2·5	3·0
1	33	41	47	58	67	75	82
$1\frac{1}{2}$	92	113	130	159	184	205	226
2	189	231	267	327	377	422	462
$2\frac{1}{2}$	329	403	466	571	659	737	807
3	520	636	735	900	1039	1162	1273
4	1067	1306	1508	1817	2133	2385	2613
5	1863	2282	2635	3227	3727	4167	4564
6	2939	3600	4157	5091	5879	6573	7200

Length of Pipe = 5000 yards.

Diameter of Pipe in inches.	Supply of Gas in cube feet per hour. Pressure by the Water-Gauge in inches.				
	1·0	1·5	2·0	2·5	3·0
2	119	146	169	189	207
3	329	402	465	520	569
4	675	826	955	1067	1168
5	1179	1443	1667	1863	2041
6	1859	2277	2629	2939	3220
7	2733	3347	3865	4321	4734
8	3816	4674	5397	6034	6610
9	5123	6274	7245	8100	8873
10	6667	8165	9428	10541	11547
12	10516	12880	14872	16628	18215

DIMENSIONS OF MAINS, WITH WEIGHT OF ONE LENGTH.

Diameter in ins.	4	6	8	9	10	14	18	26
Length in feet .	9	9	9	9	9	9	9	9
Thickness in in.	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{3}{4}$
Weight in cwts.	1·36	2	3·56	4·06	4·37	7·75	11·75	13·25

Ventilation of Tunnels.

(Morrison, 'Min. Inst. Civ. Eng.,' vol. xliv.)

H = Head in feet of pressure of air of same density as the flowing air.

D = Diameter of tunnel in feet.

L = Length of pipe or passage in feet.

P = Perimeter of cross-section in feet.

A = Area of pipe or passage in feet.

V = Velocity in thousands of feet per minute.

K = Coefficient of friction = ·03.

$$H = \frac{K V^2 P L}{A} ; \frac{K V^2 4 L}{D} ; \text{ for circular section.}$$

On a portion of the Metropolitan Railway, ½ mile long, with 30 trains per day, the velocity of the air should be 400 feet per minute. In a tunnel 7 miles long, with 16 trains per day, a current of 410 feet per minute would be needed.

When long tunnels without shafts have to be ventilated, a current of air should be passed through a fan placed near one end of the tunnel and the end closed with doors.

For a given amount of traffic the power required to ventilate varies as the fourth power of the length. For purposes of ventilation, a double line is better than two separate single-line tunnels.

For a given length of line there is a limit in the number of trains, beyond which ventilation becomes impossible. This limit cannot be defined, but for a tunnel 22 miles in length it cannot exceed 20 trains per day.

Proportions of Air, Gaseous Products, and Steam in a Tunnel after the passage of 1 Train. (D. K. Clark.)

	Per foot run.		Per mile.	
	cub. ft.	lbs.	cub. ft.	lbs.
Air	473	36	2,497,440	190,080
Gaseous products..	1	·08	5280	420
Steam	1·5	·056	7840	297

VENTILATION OF TUNNELS—*continued.*

(D. K. Clark, 'Min. Inst. Civ. Eng.,' vol. xliv.)

h = Head of pressure in inches of water.
= 5·20 lbs. per square foot per inch.
V = Velocity of current in feet per second.
P = Perimeter of tunnel in feet.
A = Sectional area of tunnel in square feet.
HP = Horse-power.
L = Length of tunnel in feet.

$$h = \frac{V^2 P L}{633000 A}. \quad HP = \frac{V^3 P L^*}{67{,}000{,}000} = \frac{V A h}{106};$$ for ventilation with brattices, $$HP = \frac{V^3 P L}{10{,}000{,}000}.$$

RADIATION OF HEAT.

(Anderson, 'Min. Inst. Civ. Eng.,' vol. xlviii.)

T = Temperature of air surrounding pipes.
t = Difference of temperature of air and that of pipes.
m = Coefficient of radiation.
u = Total units emitted per square foot by radiation and convection.

$$u = m \times 1{\cdot}00427^{T}(1{\cdot}00427^{t} - 1) + {\cdot}2853 \times t^{1{\cdot}233}.$$

$$m = \frac{u - 0{\cdot}2853 \times t^{1{\cdot}233}}{1{\cdot}00427^{T}(1{\cdot}00427^{t} - 1)}.$$

(1) m = 270·9 for a single coil of 2-in. galvanized pipe.
(2) = 252·9 for the same, with a vertical sheet of iron between the coils.
(3) = 241·0 The same as No. 1, blackleaded.
(4) = 235·3 The same as No. 2, blackleaded.
(5) = 231·8 The same as No. 1, with a similar coil.
(6) = 121·7 for a coil of 4-in. cast-iron pipes.
(7) = 123·0 Coil of 2-in. cast-iron pipe, blackleaded.
(8) = 108·8 Same as No. 7.
(9) = 272·3 2-in. wrought-iron tubes connecting two cast-iron steam-chests.

* Actual; 2½ times this horse-power should be provided.

VENTILATION.

Each person requires at least from 3 to 4 cube feet of air per minute. Ordinary windows allow about 8 cube feet a minute to pass.

WARMING BY STEAM.

When the external temperature is 10° below freezing point, in order to maintain a temperature of 60°:—

One superficial foot of steam-pipe for each 6 superficial feet of glass in the windows.

One superficial foot of ditto for every 6 cube of air escaping for ventilation per minute.

One superficial foot of ditto for every 120 feet of wall, roof, or ceiling.

One cube foot of boiler is required for every 2000 cube feet of space to be heated.

One horse-power boiler is sufficient for 50,000 cube feet of space.—Steam should be about 212°.

WARMING BY HOT WATER.

P = Temperature of pipes.
T = Temperature required in building.
t = Temperature of external air.
C = Cube feet of air to be warmed per minute.
L = Length of pipe in feet.

$$L = \frac{(P - t)(T - t)}{P - T} \times \cdot 0045\, C. \text{ for 4-in. pipes.}$$

$$L = \frac{(P - t)(T - t)}{P - T} \times \cdot 006 \quad \text{,,} \quad \text{3-in.} \quad \text{,,}$$

$$L = \frac{(P - t)(T - t)}{P - T} \times \cdot 009 \quad \text{,,} \quad \text{2-in.} \quad \text{,,}$$

Heat.

Conducting power of substances, slate being 1000.

Slate	1000	Fire-brick	620
Lead	5210	Chalk	564
Flagstone	1110	Asphalte	451
Portland stone ..	750	Oak	336
Brick	600 to 730	Lath and plaster .	255
		Cement	200

Properties of Metals, &c.

	Specific Heat.	Conducting Power.	Expansion between 32° and 212° F.	Melting Point, Fah.
Water at 39°, being	1·00	—	·04775	32°
Antimony	·0507	—	·0011	810
Bismuth	·0288	—	·0014	495
Brass	—	—	·002	1834
Copper	·095	898	·0018	1950
Gold	·0298	1000	·0016	2100
Iron, cast	—	—	·0011	2786
„ wrought ..	·113	347	·0012	—
Lead	·0293	180	·0028	612
Mercury	·033	—	·018153	$-38\frac{1}{2}$
Platinum	—	—	·0009	3080
Silver	·0557	973	·0019	1873
Tin	·0514	304	·0021	442
Zinc	·0927	363	·0029	736

Thermometer.

To convert degrees, Centigrade or Reaumur, into degrees Fahrenheit.

Let F = No. of degrees Fahrenheit.
C = „ „ Centigrade.
R = „ „ Reaumur.

$$F = \frac{9\,C}{5} + 32. \qquad F = \frac{9\,R}{4} + 32 = C + R + 32$$

$$C = \frac{5\,(F - 32)}{9}. \qquad R = \frac{4\,(F - 32)}{9}.$$

Freezing point, or 32° Fah. = Zero in Cent., or Reaumur.
Boiling point, or 212° Fah. = 100° Cent., or 80° Reaumur.

Comparison of Different Thermometers.

Centigrade or Celsius.	Reaumur.	Fahrenheit.	Centigrade or Celsius.	Reaumur.	Fahrenheit.
+260	+208	+500	+225	+180	+437
259	207·20	498·20	224	179·20	435·20
258	206·40	496·40	223	178·40	433·40
257	205·60	494·60	222	177·60	431·60
256	204·80	492·80	221	176·80	429·80
255	204	491	220	176	428
254	203·20	489·20	219	175·20	426·20
253	202·40	487·40	218	174·40	424·40
252	201·60	485·60	217	173·60	422·60
251	200·80	483·80	216	172·80	420·80
250	200	482	215	172	419
249	199·20	480·20	214	171·20	417·20
248	198·40	478·40	213	170·40	415·40
247	197·60	476·60	212	169·60	413·60
246	196·80	474·80	211	168·80	411·80
245	196	473	210	168	410
244	195·20	471·20	209	167·20	408·20
243	194·40	469·40	208	166·40	406·40
242	193·60	467·60	207	165·60	404·60
241	192·80	465·80	206	164·80	402·80
240	192	464	205	164	401
239	191·20	462·20	204	163·20	399·20
238	190·40	460·40	203	162·40	397·40
237	189·60	458·60	202	161·60	395·60
236	188·80	456·80	201	160·80	393·80
235	188	455	200	160	392
234	187·20	453·20	199	159·20	390·20
233	186·40	451·40	198	158·40	388·40
232	185·60	449·60	197	157·60	386·60
231	184·80	447·80	196	156·80	384·80
230	184	446	195	156	383
229	183·20	444·20	194	155·20	381·20
228	182·40	442·40	193	154·40	379·40
227	181·60	440·60	192	153·60	377·60
226	180·80	438·80	191	152·80	375·80

Comparison of Thermometers—*continued.*

Centigrade or Celsius.	Reaumur.	Fahrenheit.	Centigrade or Celsius.	Reaumur.	Fahrenheit.
+190	+152	+374	+155	+124	+311
189	151·20	372·20	154	123·20	309·20
188	150·40	370·40	153	122·40	307·40
187	149·60	368·60	152	121·60	305·60
186	148·80	366·80	151	120·80	303·80
185	148	365	150	120	302
184	147·20	363·20	149	119·20	300·20
183	146·40	361·40	148	118·40	298·40
182	145·60	359·60	147	117·60	296·60
181	144·80	357·80	146	116·80	294·80
180	144	356	145	116	293
179	143·20	354·20	144	115·20	291·20
178	142·40	352·40	143	114·40	289·40
177	141·60	350·60	142	113·60	287·60
176	140·80	348·80	141	112·80	285·80
175	140	347	140	112	284
174	139·20	345·20	139	111·20	282·20
173	138·40	343·40	138	110·40	280·40
172	137·60	341·60	137	109·60	278·60
171	136·80	339·80	136	108·80	276·80
170	136	338	135	108	275
169	135·20	336·20	134	107·20	273·20
168	134·40	334·40	133	106·40	271·40
167	133·60	332·60	132	105·60	269·60
166	132·80	330·80	131	104·80	267·80
165	132	329	130	104	266
164	131·20	327·20	129	103·20	264·20
163	130·40	325·40	128	102·40	262·40
162	129·60	323·60	127	101·60	260·60
161	128·80	321·80	126	100·80	258·80
160	128	320	125	100	257
159	127·20	318·20	124	99·20	255·20
158	126·40	316·40	123	98·40	253·40
157	125·60	314·60	122	97·60	251·60
156	124·80	312·80	121	96·80	249·80

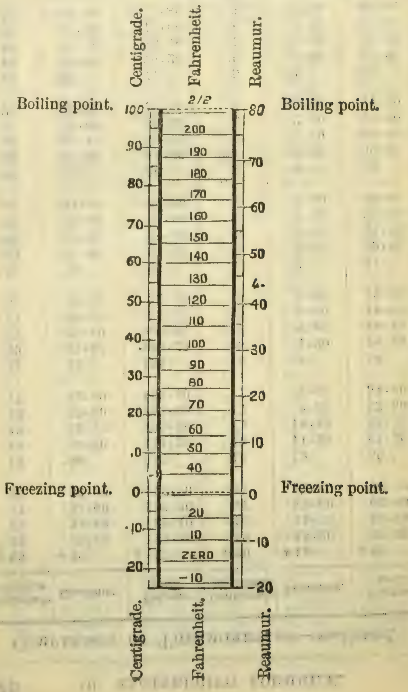
Comparison of Thermometers—*continued.*

Centigrade or Celsius.	Reaumur.	Fahrenheit.	Centigrade or Celsius.	Reaumur.	Fahrenheit.
+120	+96	+248	+85	+68	+185
119	95·20	246·20	84	67·20	183·20
118	94·40	244·40	83	66·40	181·40
117	93·60	242·60	82	65·60	179·60
116	92·80	240·80	81	64·80	177·80
115	92	239	80	64	176
114	91·20	237·20	79	63·20	174·20
113	90·40	235·40	78	62·40	172·40
112	89·60	233·60	77	61·60	170·60
111	88·80	231·80	76	60·80	168·80
110	88	230	75	60	167
109	87·20	228·20	74	59·20	165·20
108	86·40	226·40	73	58·40	163·40
107	85·60	224·60	72	57·60	161·60
106	84·80	222·80	71	56·80	159·80
105	84	221	70	56	158
104	83·20	219·20	69	55·20	156·20
103	82·40	217·40	68	54·40	154·40
102	81·60	215·60	67	53·60	152·60
101	80·80	213·80	66	52·80	150·80
100	80	212	65	52	149
99	79·20	210·20	64	51·20	147·20
98	78·40	208·40	63	50·40	145·40
97	77·60	206·60	62	49·60	143·60
96	76·80	204·80	61	48·80	141·80
95	76	203	60	48	140
94	75·20	201·20	59	47·20	138·20
93	74·40	199·40	58	46·40	136·40
92	73·60	197·60	57	45·60	134·60
91	72·80	195·80	56	44·80	132·80
90	72	194	55	44	131
89	71·20	192·20	54	43·20	129·20
88	70·40	190·40	53	42·40	127·40
87	69·60	188·60	52	41·60	125·60
86	68·80	186·80	51	40·80	123·80

COMPARISON OF THERMOMETERS—*continued.*

Centigrade or Celsius.	Reaumur.	Fahrenheit.	Centigrade or Celsius.	Reaumur.	Fahrenheit.
+50	+40	+122	+20	+16	+68
49	39·20	120·20	19	15·20	66·20
48	38·40	118·40	18	14·40	64·40
47	37·60	116·60	17	13·60	62·60
46	36·80	114·80	16	12·80	60·80
45	36	113	15	12	59
44	35·20	111·20	14	11·20	57·20
43	34·40	109·40	13	10·40	55·40
42	33·60	107·60	12	9·60	53·60
41	32·80	105·80	11	8·80	51·80
40	32	104	10	8	50
39	31·20	102·20	9	7·20	48·20
38	30·40	100·40	8	6·40	46·40
37	29·60	98·60	7	5·60	44·60
36	28·80	96·80	6	4·80	42·80
35	28	95	5	4	41
34	27·20	93·20	4	3·20	39·20
33	26·40	91·40	3	2·40	37·40
32	25·60	89·60	2	1·60	35·60
31	24·80	87·80	1	0·80	33·80
30	24	86	0	0	32
29	23·20	84·20	−1	-0·80	30·20
28	22·40	82·40	2	1·60	28·40
27	21·60	80·60	3	2·40	26·60
26	20·80	78·80	4	3·20	24·80
25	20	77	5	4	23
24	19·20	75·20	6	4·80	21·20
23	18·40	73·40	7	5·60	19·40
22	17·60	71·60	8	6·40	17·60
21	16·80	·80	9	7·20	15·80
			10	8	14

Comparative Scale of English and French Thermometers.



Light.

Velocity of light 192,000 miles per second, nearly.

Decomposition of Light.

Violet = maximum chemical ray
Indigo.
Blue.
Green.
Yellow = maximum light ray.
Orange.
Red = maximum heat ray.

Combinations of Colour.

Primary.	Secondary.	Tertiary.
Red.	Orange.	Brown.
Yellow.	Purple.	Grey.
Blue.	Green.	Broken green.

Contrasts of Colour.

Primary Colours.	Secondary in contrast to Primary.	Tertiary in contrast to Secondary.
Red.	Green.	Brown.
Yellow.	Purple.	Grey.
Blue.	Orange.	Broken green.

Sound.

Velocity of sound in air	=	1,142	feet per second.
" " water	=	4,900	"
" " wet sand	=	825	"
" " contorted rock	=	1,090	"
" " discontinuous granite	=	1,306	"
" " solid granite..	=	1,664	"
" " iron	=	17,500	"
" " copper	=	10,378	"
" " wood	=	11,000	" (pine)
	to	16,700	" (aspen)

Distant sounds may be heard on a still day:—

Human voice	150 yards.
Rifle	5,300 "
Military band	5,200 "
Cannon	35,000 "

GRAVITY.

N = Number of seconds.
S = Space fallen through in feet.
V = Velocity in feet per second, acquired in N seconds, or S space.

$V = N \times 32 \cdot 2.$

$V = \sqrt{S \times 64 \cdot 4} = 8 \cdot 025 \sqrt{S}.$

$S = N^2 \times 16 \cdot 1.$

These formulæ are approximate, varying with the latitude and elevation. See next page.

TABLE OF VELOCITY OF FALLING BODIES.

Time in seconds .	1	2	3	4	5	6	7	8	9	10
Space in feet ..	16	64	145	257	402	580	789	1030	1303	1609
Velocity in feet per second ..	32	64	96	129	161	193	225	257	290	322

FALLING BODIES.

Velocities due to Different Heights.

Fall in feet.	Velocity. Feet per second.	Fall in feet.	Velocity. Feet per second.	Fall in feet.	Velocity. Feet per second.
1	8	50	57	275	133
2	11·3	60	62	300	139
3	13·9	70	67	325	144
4	16	80	72	350	150
5	18	90	76	375	155
10	25	100	80	400	160
15	31	125	90	450	170
20	36	150	98	500	179
25	40	175	106	550	188
30	44	200	113	600	196
35	47	225	120	800	227
40	51	250	127	1000	254

Gravity.

L = Latitude.
H = Elevation above sea-level in feet.
R = Radius of earth in feet.
g = Force of gravity, feet per second.
g = 32·1889 at London at the level of the sea.

$$g = 32{\cdot}088\,(1 + {\cdot}005133\,\sin^2 . L)\left(1 - \frac{2\,H}{R}\right).$$

R = 20,923,000 at the equator.
= 20,853,000 at the poles.
= 20,888,000 mean radius.

Centrifugal Force.

W = Weight of revolving body in lbs.
R = Radius or distance from centre of motion in feet.
N = Number of revolutions per minute.
F = Centrifugal force in lbs.

$$F = {\cdot}00034\, W\, R\, N^2.$$

$$W = \frac{2941\, F}{R\, N^2}.$$

Momentum

Is the mass of any body multiplied by its velocity in units of distance (for example, by feet per second).

Impulse

Is the force (say feet per second) multiplied by the time during which it acts.

Accumulated Work.

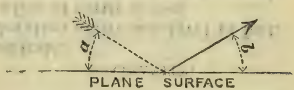
w = Weight of body in lbs.
v = Velocity of body in feet per second.
h = Height in feet through which the body descends.
x = Distance in feet to which any obstacle is moved by the body.
F = Force imparted by accumulated work in lbs.
W = Accumulated work in foot-lbs.

$$W = h\,w = \frac{w\,v^2}{64 \cdot 4}; \quad F = \frac{W}{x}.$$

Collision of Bodies.

W = Weight of one body.
V = Velocity of one body before impact.
Y = Velocity of one body after impact.
K = Coefficient of one body.
w = Weight of the other body.
v = Velocity of the other body before impact.
y = Velocity of the other body after impact.
k = Coefficient of elasticity of the other body.
= o for a non-elastic body, = 1 for a perfectly elastic body.

When a body strikes a plane surface it rebounds at an angle equal to that at which it struck the plane; in other words, the angle of incidence a = the angle of reflection b.



Collision of Bodies—*continued*. (For notation see previous page.)

Conditions.	Non-elastic Bodies.	Elastic Bodies.
One body in motion.	$y = \frac{W\,V}{W + w}$.	$y = \frac{W\,V\,(1 + k)}{W + w}$. $Y = \frac{V\,(W - K\,w)}{W + w}$.
Bodies moving in the same direction.	$y = \frac{W\,V + w\,v}{W + w}$.	$y = \frac{W\,V\,(1 + k) + v\,(w - k\,W)}{W + w}$. $Y = \frac{V\,(W - K\,w) + v\,w\,(1 + K)}{W + w}$.
Bodies moving in contrary directions.	$y = \frac{W\,V - w\,v}{W + w}$.	$y = \frac{W\,V\,(1 + k) - v\,(w - k\,W)}{W + w}$. $Y = \frac{V\,(W - K\,w) - v\,w\,(1 + K)}{W + w}$.

When the bodies are inelastic their velocity after impact will be alike, or $Y = y$.

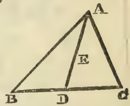
CENTRE OF GRAVITY (Homogeneous Substances).

$P =$ The volume of any particle.
$d =$ The distance of P from any given plane.
$\Sigma =$ Sum.
$x =$ The distance of the centre of gravity of the whole mass from a given plane.

$$x = \frac{\Sigma(P d)}{\Sigma P} = \frac{P d + P_1 d_1 + P_2 d_2 + \&c.}{P + P_1 + P_2 + \&c.}$$

TO FIND THE CENTRE OF GRAVITY IN A TRIANGLE.

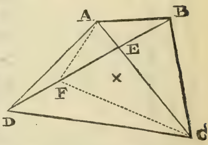
Bisect the base B C at D, and join A D. The centre of gravity lies in the line A D at E, D E being $\frac{1}{3}$rd of A D; or bisect each side and join each apex with the centre of the opposite side. The intersection of these lines will give the centre of gravity.



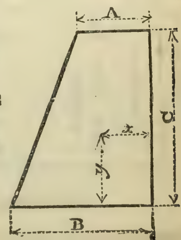
IN A PARALLELOGRAM, OR ANY FOUR-SIDED FIGURE.

In a parallelogram the intersection of the diagonals gives the centre of gravity.

In any four-sided figure A B C D draw the diagonals intersecting at E. Lay off D F = B E, and join F A, F C; then the centre of gravity of the triangle F A C is also the centre of gravity of the figure A B C D.



CO-ORDINATES OF THE CENTRE OF GRAVITY.



$$x = \frac{1}{3}\left(A + B - \frac{A B}{A + B}\right)$$

$$y = \frac{C}{3}\left(\frac{2 A + B}{A + B}\right).$$

CENTRE OF GRAVITY—*continued.*

POSITION OF CENTRE OF GRAVITY IN VARIOUS FIGURES.

Parabola .. .. .. $= \frac{2}{5}$ height from base.
Pyramid or cone .. .. $= \frac{1}{4}$ "
Paraboloid .. .. .. $= \frac{1}{3}$ "
Hemisphere .. .. .. $= \frac{3}{8}$ "

Segment of circle from centre .. .. .. $= \dfrac{\text{Chord}^3}{12 \text{ Area}}$

Sector of circle from centre .. .. .. $= \dfrac{2 \text{ Chord} \times \text{Rad.}}{3 \text{ Arc}}$

Quadrant sector .. .. $= \cdot 6002$ Rad.
$\frac{1}{6}$ circle sector .. .. $= \cdot 6366$ Rad.
Semicircle .. .. .. $= \cdot 4244$ Rad.

Circular disc ring from centre .. $= \cdot 4244 \left(\dfrac{R^3 - r^3}{R^2 - r^2}\right)$, when R and r = radii of outside and inside of ring.

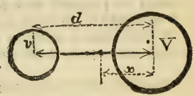
Squares, rectangles, cubes, equilateral triangles, rings, regular polygons, circles, cylinders, have their centre of gravity in their geometrical centres.

TO FIND THE CENTRE OF GRAVITY BY EXPERIMENT.

Suspend the body successively in two or more positions; then the intersection of the vertical lines from each point of suspension will pass through the centre of gravity.

TO FIND THE COMMON CENTRE OF GRAVITY OF TWO BODIES.

V = Volume of one body.
v = Volume of the other.
d = Distance of the respective centres of gravity apart.
x = Distance of common centre of gravity from centre of gravity of V.

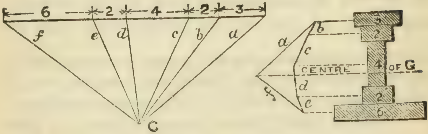


$$x = \frac{d\,v}{V + v}.$$

Centre of Gravity. (By Graphic Construction.)

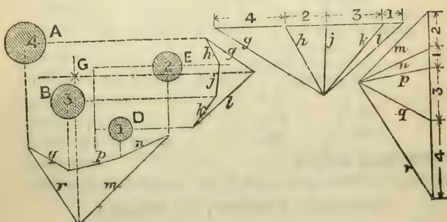
Divide the section into any convenient layers and construct a polygon of forces as follows:—

With any convenient scale set out on a horizontal line lengths corresponding with the area of each layer; assume any convenient point C, and draw lines from the lengths thus set out radiating to C. Then lines drawn parallel to these radiating lines, as shown in the diagram, intersecting the horizontal lines that pass through the centre of gravity of each layer respectively form the polygon of forces, and the intersection of the lines $a\ f$ gives the horizontal line of the centre of gravity of the layers.



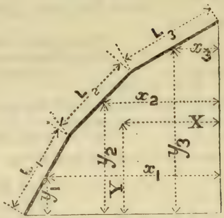
The centre of gravity of any number of bodies A B D E may be found by constructing a polygon of forces in a similar manner for horizontal as well as for vertical forces, the intersection of the two lines of polygons giving the centre of gravity at G.

FOR VERTICAL FORCES.



FOR HORIZONTAL FORCES.

To Find the Centre of Gravity of a Series of Lines.



L_1, L_2, L_3 = The lengths of the lines respectively.

x_1, x_2, x_3 = The horizontal distances of the centres of the lines respectively from the vertical axis.

y_1, y_2, y_3 = The vertical height of the centres of the lines respectively from the horizontal axis.

X = Horizontal distance of the centre of gravity of the lines from axis.

Y = Vertical height of ditto.

$$X = \frac{L_1 x_1 + L_2 x_2 + L_3 x_3}{L_1 + L_2 + L_3}.$$

$$Y = \frac{L_1 y_1 + L_2 y_2 + L_3 y_3}{L_1 + L_2 + L_3}.$$

Moment of Inertia and Centre of Gyration.

m = Mass of any particle.
M = Mass of the whole body.
d = Distance of any particle m from axis of rotation.
Σ = Sum.
R = Radius of gyration.
I = Moment of inertia of the whole of the particles.

$$I = \Sigma (m\,d^2) = m\,d^2 + m_{,}\,d_{,}^2 + m_{,,}\,d_{,,}^2 + \text{\&c.}$$

$$R = \sqrt{\frac{I}{M}}.$$

I_1 = Moment of inertia about an axis passing through the centre of gravity.
I_2 = Moment of inertia about a parallel axis at a distance y from the centre of gravity.
y = Distance of centre of gravity from the axis of rotation.

$$I_2 = I_1 + M\,y^2.$$

Centre of Gyration from Centre of Motion.

In a bar revolving about one end ..	= ·577 length.
" " centre ..	= ·289
Circular plate revolving about centre	= ·707 radius.
" " its diameter	= ·5
Sphere about its diameter	= ·6324
Hollow sphere (insensibly thick) ..	= ·816
Cylinder revolving about its axis ..	= ·707
Cone " " ..	= ·548 radius of base.
Cone (right angled) revolving about its apex	= ·866 height.

To find the Specific Gravity of a Substance.

W = Weight of body in air. w = Weight of body in water.

$$\text{Specific gravity} = \frac{W}{W - w}.$$

If the substance be lighter than the water, sink it by means of a heavier substance, and deduct the weight of the heavier substance. Weight of a cubic foot in lbs. = specific gravity × 62·425.

Centre of Percussion and Oscillation.

I = Moment of inertia.
d = Distance of the centre of gravity from the axis of motion.
M = Volume of body.
x = Distance of centre of oscillation or percussion from the axis.

$$x = \frac{I}{M\,d}$$

Distance from centre of motion in a straight bar suspended at extremity, $\frac{2}{3}$ length.
Very slender cones suspended at apex, $\frac{4}{5}$ height.

Pendulum.

l = Length of pendulum in feet.
L = " " in inches.
T = Time of one oscillation in seconds.
N = Number of oscillations per minute.
g = Gravity. (Approximately $= 32 \cdot 2$ if feet or $386 \cdot 4$ if inches be required.)

$$T = \cdot 16 \sqrt{L} = \pi \sqrt{\frac{l}{g}}.$$

$$T = \cdot 554 \sqrt{l}.$$

$$l = g\left(\frac{T}{\pi}\right)^2 ; \; L = \left(\frac{375 \cdot 36}{N}\right)^2.$$

$$N = \frac{375 \cdot 36}{\sqrt{L}}.$$

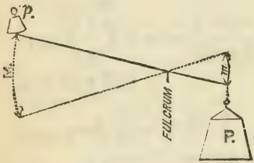
$l = 39 \cdot 1383$ inches in the latitude of London.

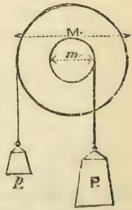
$g = 32 \cdot 088\,(L + \cdot 005133\,\mathrm{Sin}^2\lambda)\left(1 - \frac{2h}{R}\right)$

λ = Latitude; h = Height above the Sea in feet.
R = Radius of Earth = 20,900,000 feet.

Mechanical Powers.

The effect of power transmitted by either the lever, pulley, inclined plane, wedge, screw, or wheel, and axle, may be reduced in all cases to one rule, *viz.* the gain of power is directly proportioned to the loss of motion, and *vice versâ.*





p = Power applied.
P = Power transmitted.
M = Motion of (p) power applied.
m = Motion of (P) power transmitted.

$$P = \frac{M\,p}{m}.$$

This of course does not include friction. The diagrams show the application in the case of the lever and wheel and axle.

Millwork.

Number of Teeth in Wheels.

N = Number of teeth in driving wheel.
n = Number of teeth in driven wheel.
V = Revolutions of driving wheel.
v = Revolutions of driven wheel.

$$n = \frac{N\,V}{v}. \qquad v = \frac{N\,V}{n}.$$

STRENGTH OF TEETH OF WHEELS. (Cast Iron.)

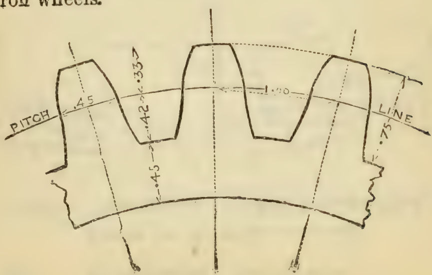
B = Breadth of teeth from $2\frac{1}{2}$ P. to $3\frac{1}{2}$ P.
P = Pitch of teeth in inches.
V = Velocity of pitch line in feet per second.
H = Actual horse-power which may be transmitted by wheel.

$H = 0 \cdot 6\, P^2\, V.$ $\qquad P = \sqrt{\dfrac{H}{0 \cdot 6\, V.}}$

PROPORTIONS OF TEETH OF WHEELS.

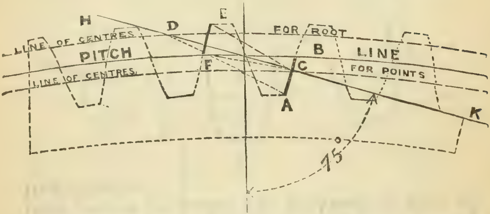
From pitch line to top of tooth ..	= Pitch × 0·33
Total depth of tooth	= Pitch × 0·75
Thickness of tooth on pitch line ..	= Pitch × 0·45
Space between teeth on pitch line	= Pitch × 0·55
Thickness of rim of wheel	= Pitch × 0·45
Thickness of arms if flat	= Pitch × 0·45
Ordinary width of teeth in small pitches	= Pitch × 2·
In large	= Pitch × 3·
Thickness round centre	= Pitch × 1·3

Mortise wheels to be wider than iron wheels by twice the thickness of the rim or by pitch × 0·9; their rim to be double the thickness of that of iron wheels.



TEETH OF WHEELS—*continued.*

(Method communicated by Mr. Aubrey Ohren.)



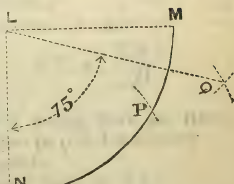
From the radial line at the edge of the tooth on the pitch line, lay off the line H K at an angle of 75° with the radial line; on this line will be the centres of the root A B and the point E F. The lines struck from these centres are shown in thick lines. Circles drawn through centres thus found will give the lines in which the remaining centres will be.

The radius D A for striking the root A B is = pitch + the thickness of the tooth.

The radius C E for striking the point of the tooth E F = the pitch.

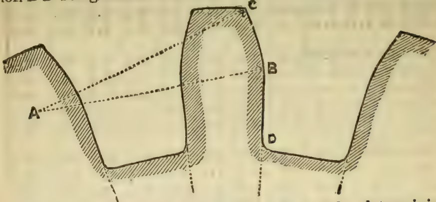
TO DESCRIBE THE ANGLE OF 75° WITHOUT A PROTRACTOR.

Describe a quarter of a circle M N with any radius L M, and from N with a radius = L M, strike a portion of a circle intersecting the circle M N at P; then from the points P and M as centres with any equal radii strike out two portions of circles intersecting each other at Q; the line joining L Q will be at an angle of 75° with L N.



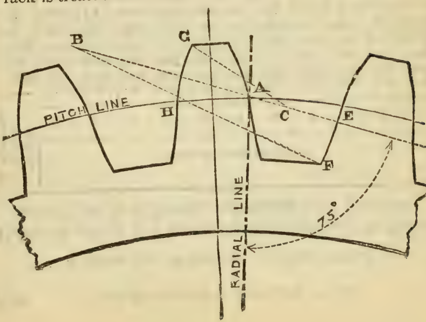
Teeth of Wheels,

If *not* made epicycloidal, are frequently struck out with compasses, the pitch point A being the centre from which the point of the next tooth B C is struck with radius A B, the portion B D being radial.



The following plan is adopted in America for determining the curves of teeth: P = Pitch, N = No. of teeth. Set off from the pitch line at A, a line B A C at an angle of 75° with a line radiating from the centre of the wheel to the edge of the tooth; lay off from A, $AB = \frac{P(N+6)}{2(N-11)}$, and $AC = \cdot 11 P \sqrt[3]{N}$.

From centre B strike out E F, and from centre C strike out G H. A rack is treated as a wheel of 200 teeth.



Teeth of Wheels. (Cast Iron.)

Table showing the horse-power that may be transmitted, with different velocities and pitches.

Velocity in feet per second.	Pitch of Teeth in inches.										
	¾	1	1¼	1½	1¾	2	2½	3	4	5	6
	h.-p.	h.-p.	h.-p.	h.-p.	h.-p.	h.-p.	h.-p.	h.-p.	h.-p.	h.-p.	h.-p.
·025	·008	·015	·023	·033	·045	·060	·093	·135	·240	·37	·54
·05	·017	·030	·047	·067	·09	·12	·18	·27	·48	·75	1·08
·075	·025	·045	·07	·101	·138	·18	·281	·40	·72	1·12	1·62
·1	·033	·06	·094	·135	·184	·24	·375	·54	·96	1·5	2·16
·2	·067	·12	·188	·270	·366	·48	·75	1·08	1·9	3·0	4·3
·3	·10	·18	·28	·40	·55	·72	1·1	1·6	2·8	4·5	6·4
·4	·13	·24	·37	·54	·73	·96	1·5	2·1	3·8	6·0	8·6
·5	·17	·30	·47	·67	·91	1·2	1·8	2·7	4·8	7·5	10·8
·6	·20	·36	·56	·81	1·1	1·4	2·2	3·2	5·7	9·0	12·9
·7	·23	·42	·65	·94	1·28	1·68	2·6	3·7	6·7	10·5	15·1
·8	·27	·48	·75	1·1	1·4	1·9	3·0	4·3	7·6	12·0	17·2
·9	·30	·54	·84	1·2	1·6	2·1	3·3	4·8	8·6	13·5	19·4
1·0	·33	·6	·94	1·35	1·8	2·4	3·7	5·4	9·6	15·	21·6
1·2	·40	·72	1·1	1·6	2·1	2·8	4·5	6·4	11·5	18·	25·9
1·4	·47	·84	1·3	1·8	2·5	3·3	5·2	7·5	13·4	21·0	30·2
1·6	·54	·96	1·5	2·1	2·9	3·8	6·0	8·6	15·3	24·0	34·5
1·8	·61	1·1	1·7	2·4	3·3	4·3	6·7	9·7	17·3	27·0	38·9
2·0	·66	1·2	1·9	2·7	3·6	4·8	7·5	10·8	19·2	30·0	43·2
2·2	·74	1·3	2·1	2·9	4·0	5·3	8·2	11·9	21·1	33·0	47·5
2·4	·81	1·4	2·2	3·2	4·4	5·7	9·0	12·9	23·0	36·0	51·8
2·6	·88	1·5	2·4	3·5	4·7	6·2	9·7	14·0	24·9	39·0	56·1
2·8	·95	1·6	2·6	3·7	5·1	6·7	10·5	15·1	26·9	42·0	60·4
3·0	1·01	1·8	2·8	4·0	5·5	7·2	11·2	16·2	28·8	45·0	64·8
3·5	1·2	2·1	3·3	4·7	6·4	8·4	13·1	18·9	33·6	52·5	75·6
4·0	1·3	2·4	3·7	5·4	7·3	9·6	15·0	21·6	38·4	60·0	86·4

Construction of the Teeth of Wheels.

EPICYCLOIDAL TEETH.

In making a set of wheels, the teeth of all wheels of the same pitch that may be required to work together should be generated by the same rolling circle.

The best diameter of the rolling circle for any pitch = pitch × 2·22, unless any wheel in the set should have less than fourteen teeth. No wheel should have less than fourteen teeth, but if it is unavoidable, in that case the diameter of the rolling circle may be determined by the following formula:

D = Diameter of rolling circle.
P = Pitch of teeth.
N = Number of teeth in the smallest wheel of the set.

$$D = \frac{N\,P}{6 \cdot 3}.$$

The diameter of the rolling circle must in no case exceed the radius of the least pitch circle in the set. The plan of making the rolling circle equal to the pitch circle is incorrect.

Nature of Curves of Teeth.

	Curve of Root.	Curve of Point.
In a straight rack	Cycloidal	Cycloidal.
In a wheel	Hypocycloidal ..	Epicycloidal.
In an internal segment..	Epicycloidal.. ..	Hypocycloidal.

In the workshop the curves of the teeth are struck out by rolling the template of the generating or rolling circle on a template corresponding with the pitch line. A scriber or pencil on the periphery of the generating circle marking out the required curve.

EPICYCLOIDAL TEETH.

The curves of epicycloidal teeth are generated by a point in the circumference of a circle (called the rolling circle) which rolls on the pitch line of the teeth to be described.

To Delineate the Required Curves by Construction.

From the centre C, with radius C B, draw the pitch line A B. From any point, y, lay off on the pitch line, any convenient points, $d\ e\ f\ g\ h$, at any distances from one another, and from them draw the radial lines C d C e C f C g C h; and, with their centres on these radial lines, describe circles equal to the rolling circle, and touching the pitch line at the points $d\ e\ f\ g\ h$.

On the circumference of the circle	at d	set off	$d\ j = y\ d$
,, ,,	at e	,,	$e\ k = y\ e$
,, ,,	at f	,,	$f\ l = y\ f$
,, ,,	at g	,,	$g\ m = y\ g$
,, ,,	at h	,,	$h\ n = y\ h$

The points $y\ j\ k\ l\ m\ n$ form the required curve for the root of the teeth.

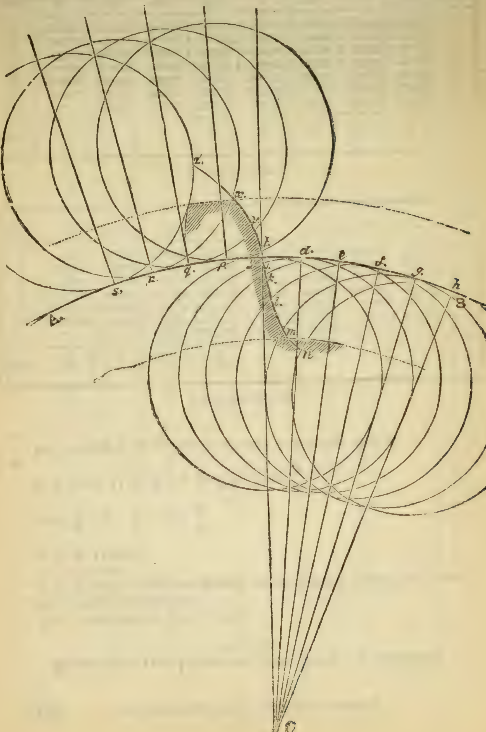
Also set off, in like manner, the points $p\ q\ r\ s$, and through these points draw radial lines, and, with their centres on these radial lines, describe circles equal to the rolling circle, and touching the pitch line at the points $p\ q\ r\ s$.

On the circumference of the circle	at p	lay off	$p\ t = y\ p$
,, ,,	at q	,,	$q\ v = y\ q$
,, ,,	at r	,,	$r\ x = y\ r$
,, ,,	at s	,,	$s\ z = y\ s$

Then the points $y\ t\ v\ x\ z$ form the curve for the point of the tooth.

For straight racks instead of radial lines, perpendicular lines are used.

DIAGRAM SHOWING METHOD OF FORMING EPICYCLOIDAL TEETH.



Rules for the Diameter and Pitch of Toothed Wheels.

D = Diameter of pitch circle.
N = Number of teeth.
P = Pitch of teeth calculated as measured round the pitch circle.

$\pi = 3 \cdot 14159$;

$x = \frac{\pi}{P}$; $y = \frac{P}{\pi}$; $z = \frac{N}{\pi}$.

$N = Dx$; $D = Ny$; $= Pz$; $P = \frac{D}{z}$.

For values of x, y, and z, see the following tables.

Values of x.

Pitch.	0	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	Pitch.
0	—	25·1327	12·5664	8·37758	6·28319	5·02655	4·18879	3·59039	0
1	3·14159	2·79253	2·51327	2·28479	2·09440	1·93329	1·79520	1·67552	1
2	1·57080	1·47840	1·39626	1·32278	1·25664	1·19680	1·14240	1·09273	2
3	1·04720	1·00531	·96664	·93084	·89760	·86665	·83776	·81073	3
4	·78540	·76160	·73920	·71808	·69813	·67926	·66139	·64443	4
5	·62832	·61299	·59840	·58448	·57120	·55851	·54636	·53474	5
6	·52360	·51291	·50265	·49280	·48332	·47420	·46542	·45696	6
Pitch.	·0	·125	·25	·375	·5	·625	·75	·875	Pitch.

Values of y.

Pitch.	0	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	Pitch.
0	—	·03979	·07958	·11937	·15915	·19894	·23873	·27852	0
1	·31831	·35810	·39789	·43768	·47746	·51725	·55704	·59683	1
2	·63662	·67641	·71620	·75599	·79577	·83556	·87535	·91514	2
3	·95493	·99472	1·03451	1·07430	1·11408	1·15387	1·19366	1·23345	3
4	1·27324	1·31303	1·35282	1·39261	1·43239	1·47218	1·51197	1·55176	4
5	1·59155	1·63134	1·67113	1·71092	1·75070	1·79049	1·83028	1·87007	5
6	1·90986	1·94965	1·98944	2·02923	2·06901	2·10880	2·14859	2·18838	6
Pitch.	0	·125	·25	·375	·5	·625	·75	·875	Pitch.

Pitch and Diameter of Teeth of Wheels.

Values of z when pitch is measured round the pitch line.

No. of Teeth.	0	1	2	3	4	5	6	7	8	9	No. of Teeth.
0	—	·31831	·63662	·95493	1·2732	1·5915	1·9099	2·2282	2·5465	2·8648	0
10	3·1831	3·5014	3·8197	4·1380	4·4563	4·7746	5·0930	5·4113	5·7296	6·0479	10
20	6·3662	6·6845	7·0028	7·3211	7·6394	7·9577	8·2761	8·5944	8·9127	9·2310	20
30	9·5493	9·8676	10·1859	10·5042	10·8225	11·1408	11·45[illegible]2	11·7775	12·0958	12·4141	30
40	12·7324	13·0507	13·3690	13·6873	14·0056	14·3239	14·6423	14·9606	15·2789	15·5972	40
50	15·9155	16·2338	16·5521	16·8704	17·1887	17·5070	17·8254	18·1437	18·4620	18·7803	50
60	19·0986	19·4169	19·7352	20·0535	20·3718	20·6901	21·0085	21·3268	21·6451	21·9634	60
70	22·2817	22·6000	22·9183	23·2366	23·5549	23·8732	24·1916	24·5099	24·8282	25·1465	70
80	25·4648	25·7831	26·1014	26·4197	26·7380	27·0563	27·3747	27·6930	28·0113	28·3296	80
90	28·6479	28·9662	29·2845	29·6028	29·9211	30·2394	30·5577	30·8761	31·1944	31·5127	90
No. of Teeth.	0	1	2	3	4	5	6	7	8	9	No. of Teeth.

Pitches of Equivalent Strength for the Teeth of Wheels in Different Materials.

Pitch for cast iron		= 1·00
„	brass ..	= 1·12
„	hard wood	= 1·26

Shafting.

Strength of wrought-iron shafting.

D = Diameter of shaft in inches.
H = *Indicated* horse-power to be transmitted.
N = Number of revolutions per minute.

$$D = \sqrt[3]{\frac{83\,H}{N}}$$ in crank-shafts and prime movers.

$$D = \sqrt[3]{\frac{65\,H}{N}}$$ in ordinary shafting.

Relative Power of Metals to Resist Torsion, Wrought Iron being Unity.

Wrought iron ..	1·00	Brass	·25
Cast iron	·90	Copper	·22
Cast steel	1·93	Tin	·13
Gun-metal ..	·27	Lead	·10

Relative Power of Different Sections to Resist Torsion, the Sectional Areas being Equal, Solid Cylinder being Unity.

Solid Cylinders.	Solid Squares	Hollow Cylinders whose Inner Diameter is to the Outer as 4 to 10	5 to 10	6 to 10	7 to 10	8 to 10.
1·0	·87	1·26	1·44	1·7	2·08	2·74

Coefficients of Friction in Axles.

Axle.	Bearing.	Dry.	Greasy and Wetted.	Ordinary Lubrication.	Lubricated Continuously.	Pure Carriage Grease.	Lard and Plumbago.	Fatty Matter.
Bell-metal ..	Bell-metal ..	—	—	·097	—	—	—	—
Cast iron ..	" ..	—	—	—	·049	—	—	—
Wrought iron	" ..	·25	·19	·07	·05	·09	·11	—
"	Cast iron ..	—	—	·07	·05	—	—	—
Cast iron ..	" ..	—	·13	·07	·05	—	—	0·14
"	Bell-metal ..	·19	·16	·07	·05	·06	—	·16
Wrought iron	Lignum vitæ	·19	—	·12	—	—	—	—
Cast iron ..	" ..	·18	—	·10	·09	—	·11	·14
Lignum vitæ	Cast iron ..	—	—	·11	—	—	—	·15
"	Lignum vitæ	—	—	—	·07	—	—	—

Frictional Resistance of Shafting. (Webber.)

K = Coefficient of friction.
W = Work absorbed in foot-lbs.
P = Weight of shafting and pulleys + resultant stress of belts.
H = Horse-power absorbed.
D = Diameter of journals in inches.
R = Number of revolutions per minute.

	Ordinary oiling.	Continuous oiling.
W =	·0182 P D;	·0112 P D.
H =	·000000556 P D R;	·000000339 P D R.
K	·066 ;	·044.

As a rough approximation, 100 feet of shafting, 3 inches diameter, making 120 revolutions per minute, requires 1 horse-power.

Pressure on Bearings of Shafting.

Pressure on bearings should not exceed 750 lbs. per square inch, measured axially.

For pivots of upright shafts, Fairbairn limits the pressure to 240 lbs. per square inch.

Cast-iron bearings wear well if the pressure does not exceed 100 lbs. per square inch, or velocity 150 feet per minute.

Torsional Moment of Resistance for Shafts.
(E. J. Edwards.)

Calculated from the formula $M = \frac{\pi}{16} f d^3$.

M = Movement of resistance to torsion. $\pi = 3 \cdot 14159$.
f = Stress per square inch. d = Diameter of shaft in inches.
= 8000 to 10,000 lbs. for wrought iron, and 4000 to 5000 lbs. for cast iron.

Note.—The *bending* moment of resistance is half the numbers in tables, as $M = \frac{\pi}{32} f d^3$.

Diameter.	f = 8000 lbs.	f = 10000 lbs.	Diameter.	f = 8000 lbs.	f = 10000 lbs.
inches.			inches.		
1	1,570	1,962	7¼	598,293	747,866
1¼	3,066	3,832	7½	662,344	827,930
1½	5,299	6,624	7¾	730,810	913,512
1¾	8,414	10,517	8	803,840	1,004,800
2	12,560	15,700	8½	964,176	1,205,220
2¼	17,883	22,354	9	1,144,530	1,430,662
2½	24,531	30,664	9½	1,346,079	1,682,599
2¾	32,651	40,814	10	1,570,000	1,962,500
3	42,390	52,988	10½	1,817,471	2,271,839
3¼	53,895	67,369	11	2,089,670	2,612,088
3½	67,314	84,143	11½	2,387,774	2,984,717
3¾	82,793	103,491	12	2,712,960	3,391,200
4	100,480	125,600	13	3,449,290	4,311,612
4¼	120,522	150,652	14	4,308,080	5,385,100
4½	143,066	178,833	15	5,298,750	6,623,438
4¾	168,260	210,325	16	6,430,720	8,038,400
5	196,250	245,313	17	7,713,410	9,641,762
5¼	227,184	283,980	18	9,156,240	11,445,300
5½	261,209	326,511	19	10,768,630	13,460,788
5¾	298,472	373,090	20	12,560,000	15,700,000
6	339,120	423,900	21	14,539,770	18,174,710
6¼	383,300	479,125	22	16,717,360	20,896,700
6½	431,161	538,951	23	19,102,190	23,877,738
6¾	482,848	603,560	24	21,703,680	27,129,600
7	538,510	673,138			

Note.—For cast-iron shafts half the numbers to be taken.

Example.—Required to find a shaft for a drum having 2¼ tons pulling on it at 17″ radius and taking f = 8000 lbs.

The moment of weight = $W l = 2\frac{1}{4} \times 2240 \times 17 = 95{,}200$ inch-lbs.; the torsional moment of resistance must be equal or greater than this amount. Find in the table the number next higher, which in this case is 100,480 opposite 4″ diameter which will be the size of shaft required in wrought iron.

If for cast-iron shaft and f = 4000 lbs., then 5″ diameter is the size, since

$$\frac{196250}{2} = 98125.$$

Strength of Shafting to Resist Torsion.

L = Length of lever in inches, or radius of wheel at which force is applied.
F = Force applied in lbs.
D = Diameter of shaft in inches, if round.
S = Side of shaft in inches, if square.

$$D = \sqrt[3]{\frac{FL}{1700}} \text{ for wrought iron.}$$

$$S = \sqrt[3]{\frac{FL}{2000}} \text{ for wrought iron.}$$

$$D = \sqrt[3]{\frac{FL}{K}} \text{ for any other metal.}$$

$$S = \sqrt[3]{\frac{FL}{x}} \text{ for any other metal.}$$

Values of K and x.

For cast steel	$K = 3200$	$x = 3800$
„ cast iron	$K = 1500$	$x = 1800$
„ gun-metal ..	$K = 460$	$x = 540$
„ brass	$K = 425$	$x = 500$
„ copper	$K = 380$	$x = 440$
„ tin	$K = 220$	$x = 260$
„ lead	$K = 170$	$x = 200$

Supports for Ordinary Shafting.

D = Diameter of shaft in inches.
S = Distance of supports apart in feet.

$S = 4{\cdot}5 \sqrt[3]{D^2}$, where power is taken off by riggers between the supports.

$S = 5{\cdot} \sqrt[3]{D^2}$, where no power is taken off between the supports.

Dimensions of Ordinary Wrought-iron Shafting.

Revolutions per minute.	Indicated Horse-power.									
	10	20	30	40	50	60	70	80	90	100
10	4·02	5·06	5·80	6·38	6·87	7·31	7·69	8·04	8·36	8·66
20	3·21	4·02	4·61	5·06	5·46	5·8	6·11	6·38	6·64	6·87
30	2·8	3·53	4·02	4·43	4·77	5·06	5·35	5·58	5·8	6·01
40	2·57	3·17	3·66	4·02	4·34	4·61	4·85	5·06	5·28	5·46
50	2·35	2·96	3·39	3·73	4·02	4·27	4·5	4·70	4·89	5·06
60	2·22	2·8	3·21	3·53	3·80	4·02	4·23	4·43	4·61	4·77
70	2·15	2·67	3·04	3·36	3·61	3·82	4·02	4·22	4·38	4·53
80	2·04	2·57	2·92	3·21	3·45	3·66	3·85	4·02	4·20	4·34
90	2	2·46	2·80	3·07	3·33	3·53	3·71	3·87	4·02	4·18
100	1·86	2·35	2·69	2·96	3·17	3·39	3·56	3·73	3·87	4·02
120	1·76	2·22	2·57	2·8	3·03	3·21	3·36	3·53	3·66	3·80
150	1·64	2·08	2·35	2·62	2·80	2·96	3·14	3·27	3·39	3·53
170	1·58	2·0	2·29	2·52	2·67	2·84	2·96	3·14	3·27	3·39
200	1·5	1·86	2·15	2·35	2·52	2·71	2·84	2·96	3·11	3·21
250	1·36	1·82	2·0	2·22	2·35	2·52	2·62	2·75	2·88	2·96
300	1·29	1·62	1·91	2·08	2·22	2·35	2·52	2·62	2·71	2·80
350	1·26	1·59	1·82	2·0	2·15	2·29	2·35	2·46	2·57	2·67
400	1·18	1·49	1·71	1·91	2·0	2·15	2·29	2·35	2·46	2·57
500	1·08	1·44	1·59	1·83	1·91	2·0	2·15	2·22	2·29	2·35
600	1·03	1·29	1·48	1·64	1·82	1·91	2·0	2·08	2·15	2·22

Dimensions of First-motion Shafting; Crank-shafts, &c. (Wrought Iron.)

Revolutions per minute.	Indicated Horse-power.									
	10	20	30	40	50	60	70	80	90	100
10	4·36	5·49	6·29	6·92	7·46	7·92	8·34	8·72	9·07	9·4
20	3·46	4·36	4·99	5·49	5·91	6·29	6·62	6·92	7·19	7·46
30	3·02	3·81	4·36	4·8	5·17	5·49	5·78	6·05	6·29	6·52
40	2·75	3·46	3·96	4·36	4·71	4·99	5·25	5·49	5·72	5·92
50	2·55	3·21	3·68	4·05	4·36	4·64	4·88	5·1	5·31	5·49
60	2·4	3·02	3·46	3·81	4·11	4·36	4·59	4·8	4·99	5·17
70	2·28	2·86	3·28	3·62	3·9	4·15	4·36	4·56	4·75	4·92
80	2·17	2·75	3·14	3·46	3·72	4·00	4·18	4·36	4·54	4·7
90	2·09	2·64	3·01	3·33	3·59	3·81	4·02	4·2	4·36	4·51
100	2·03	2·55	2·92	3·21	3·46	3·68	3·87	4·05	4·21	4·36
120	1·90	2·4	2·75	3·02	3·26	3·46	3·66	3·81	3·96	4·12
150	1·75	2·22	2·55	2·81	3·01	3·21	3·4	3·56	3·68	3·82
170	1·7	2·12	2·45	2·7	2·89	3·08	3·24	3·39	3·53	3·68
200	1·6	2·03	2·3	2·55	2·75	2·9	3·07	3·21	3·33	3·46
250	1·5	1·9	2·15	2·36	2·54	2·7	2·88	3·00	3·10	3·24
300	1·4	1·75	2·03	2·23	2·38	2·53	2·67	2·81	2·92	3·03
350	1·33	1·67	1·92	2·1	2·29	2·42	2·57	2·67	2·8	2·88
400	1·27	1·6	1·84	2·02	2·18	2·32	2·46	2·55	2·67	2·76
500	1·18	1·8	1·7	1·86	2·03	2·15	2·23	2·35	2·46	2·57
600	1·11	1·35	1·58	1·75	1·91	2·03	2·15	2·22	2·32	2·41

Strength of Shafting to Resist Lateral Stress.

D = Diameter in inches, or side, if square.
L = Length of shaft supported at both ends in feet.
W = Weight applied on the centre in lbs.

$$D = \sqrt[3]{\frac{L\,W}{k}}.$$

or $D = \sqrt[3]{\frac{L\,w}{2\,k}}$, where w = weight distributed in [lbs.

	Round Shafts.	Square Shafts.
For wood	$k = 40$	70
„ cast iron ..	$k = 500$	850
„ wrought iron	$k = 700$	1200

Table of Shafting.—Necks (or Journals) and Couplings.

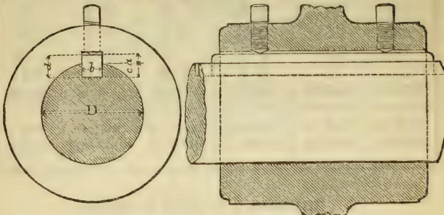
Diameter of Neck.	Length of Neck.	Diameter of Coupling.	Length of Lap.	Length of Box.	Diameter of Box.
inches.	inches.	inches.	inches.	inches.	inches.
2	4	3¼	2¼	5½	5½
2½	5	4	3	6½	6¾
3	6	4¾	3½	7½	7¾
3½	6½	5½	3¾	8	9
4	7	6	4	8½	9½
5	8	7¼	5	9½	11¼
6	9	9	6	12	13½
7	10¼	10½	7½	14	16
8	12	12	8	16½	18
9	13½	13	9	18	20
10	14¼	14	10	18½	22
11	15	16	11	20	24
12	16	17½	12	21	26

By the practice of some makers the length of neck = 1¼ diam. The neck or journal in high speed machines should be larger than given in the table; pivoted bearings are made from 3 to 4 diameters long.

Power absorbed by Shafting.

About 1 horse-power for every 100 feet of 3-inch shafting making 120 revolutions per minute.

Keys and Keyways. (J. Richards.)



D = Diameter of shaft in inches.
b = Breadth of key = ·182 D.
d = Depth of key = $b + \frac{1}{16}$ inch.
a = Depth of key in boss = ·07 D + $\frac{1}{32}$ inch, say = ·4 d.
c = Ditto in shaft = ·104 D + $\frac{1}{32}$ inch, say = ·6 d.
Clearance at the top of key = $\frac{1}{32}$ inch.

The top and bottom of the key are left rough; the sides only are fitted; the nearest 16ths as calculated above may be adopted.

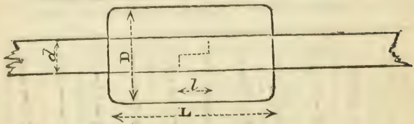
Table of Dimensions in Inches.

D	$1\frac{1}{2}$	2	$2\frac{1}{2}$	3	$3\frac{1}{2}$	4	$4\frac{1}{2}$	5	$5\frac{1}{2}$	6	7	8
b	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{13}{16}$	$\frac{15}{16}$	1	$1\frac{1}{8}$	$1\frac{5}{16}$	$1\frac{7}{16}$
d	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{13}{16}$	$\frac{15}{16}$	$1\frac{1}{16}$	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{9}{16}$
a	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$
c	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{13}{16}$	$\frac{15}{16}$

Dimensions of Eyes of Wheels and Pulleys (Staked).

Diameter of shaft	$1\frac{3}{4}$	2	$2\frac{1}{4}$	$2\frac{1}{2}$	$2\frac{3}{4}$	3	$3\frac{1}{2}$
Diameter of eye of wheel	$3\frac{1}{2}$	4	$4\frac{1}{2}$	5	$5\frac{1}{4}$	$5\frac{1}{2}$	6
Diameter of eye of pulley	$3\frac{1}{4}$	$3\frac{1}{2}$	$3\frac{3}{4}$	$4\frac{1}{4}$	$4\frac{3}{4}$	5	$5\frac{1}{2}$

Solid Couplings for Flush Joints of Shafts from $1\frac{1}{2}$ to 5 inches diameter.



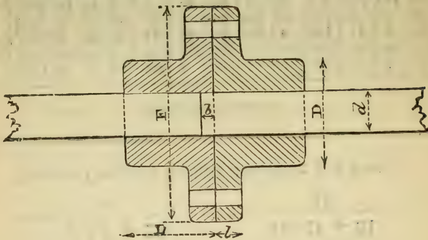
D = Diameter of box.
d = Diameter of shaft.
L = Length of box.
l = Length of lap.

$D = d + \sqrt{6\,d}$.
$L = 3\,d$.
$l = \cdot 8\,d$.
Breadth of key $= \cdot 25\,d + \cdot 12$.
Depth of ditto $= \frac{1}{2}$ breadth.

Diam. of Shaft.	Diameter of Box.	Length of Box.	Length of Lap.	Breadth of Key.	Depth of Key.
inches.	inches.	inches.	inches.	inches.	inches.
$1\frac{1}{2}$	4·5	4·5	1·2	·5	·25
2	5·4	6	1·6	·62	·31
$2\frac{1}{2}$	6·4	7·5	2·0	·75	·37
3	7·2	9	2·4	·87	·43
$3\frac{1}{2}$	8·1	10·5	2·8	1	·5
4	8·9	12	3·2	1·12	·56
$4\frac{1}{2}$	9·7	13·5	3·6	1·24	·62
5	10·5	15	4	1·37	·68

Flanged Couplings

For Shafts from $1\frac{1}{2}$ to 5 inches diameter.



d = Diameter of shaft.

D = Diameter of boss = $d + \sqrt{4\,d}$.

F = Diameter of flange = $3\,d + 2$.

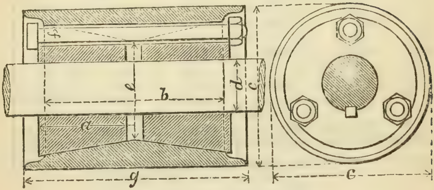
l = Thickness of flange = $\cdot 3\,d + \cdot 4$.

L = Length of boss = $d + 1$.

b = Projection of shaft = $\frac{l}{4}$.

Diameter of Shaft.	Diameter of Boss.	Length of Boss.	Diameter of Flange.	Thickness of Flange.	Projection of Shaft.
inches.	inches.	inches.	inches.	inches.	inches.
$1\frac{1}{2}$	3·9	2·5	6·5	·85	·22
2	4·8	3	8	1·0	·25
$2\frac{1}{2}$	5·6	3·5	9·5	1·15	·29
3	6·5	4	11	1·3	·32
$3\frac{1}{2}$	7·2	4·5	12·5	1·45	·36
4	8	5	14	1·6	·4
$4\frac{1}{2}$	8·7	5·5	15·5	1·75	·44
5	9·5	6	17	1·9	·48

SELLER'S COMPRESSION COUPLING.



D = Nominal diameter of shaft.
d = Actual diameter.

$$a = \frac{3\,D}{2}. \qquad e = \frac{65\,D + 38}{48}.$$

$$b = 3\,D. \qquad f = \frac{5\,D + 5}{24}.$$

$$c = \frac{115\,d + 28}{48}. \qquad g = \frac{169\,D + 31}{48}.$$

Taper of cone, 3 inches diameter per foot.

Mark.	Dimensions in Inches.														
D	$1\frac{1}{2}$	$1\frac{5}{8}$	$1\frac{3}{4}$	2	$2\frac{1}{4}$	$2\frac{1}{2}$	$2\frac{3}{4}$	3	$3\frac{1}{4}$	$3\frac{1}{2}$	4	$4\frac{1}{2}$	5	6	8
d	$1\frac{7}{16}$	$1\frac{9}{16}$	$1\frac{11}{16}$	$1\frac{15}{16}$	$2\frac{3}{16}$	$2\frac{7}{16}$	$2\frac{11}{16}$	$2\frac{15}{16}$	$3\frac{3}{16}$	$3\frac{7}{16}$	$3\frac{15}{16}$	$4\frac{7}{16}$	$4\frac{15}{16}$	$5\frac{15}{16}$	$7\frac{15}{16}$
a	$2\frac{1}{4}$	$2\frac{7}{16}$	$2\frac{9}{16}$	3	$3\frac{3}{8}$	$3\frac{3}{4}$	$4\frac{1}{8}$	$4\frac{1}{2}$	$4\frac{7}{8}$	$5\frac{1}{4}$	6	$6\frac{3}{4}$	$7\frac{1}{2}$	9	12
b	$4\frac{1}{2}$	$4\frac{7}{8}$	$5\frac{1}{8}$	6	$6\frac{3}{4}$	$7\frac{1}{2}$	$8\frac{1}{4}$	9	$9\frac{3}{4}$	$10\frac{1}{2}$	12	$13\frac{1}{2}$	15	18	24
c	$3\frac{3}{4}$	$4\frac{3}{16}$	$4\frac{5}{8}$	$5\frac{3}{8}$	$5\frac{7}{8}$	$6\frac{9}{16}$	7	$7\frac{3}{4}$	$8\frac{1}{4}$	$9\frac{1}{16}$	10	$11\frac{3}{8}$	$12\frac{9}{16}$	$14\frac{1}{2}$	$19\frac{5}{16}$
e	$2\frac{1}{4}$	$2\frac{9}{16}$	$2\frac{13}{16}$	$3\frac{1}{2}$	$3\frac{5}{8}$	4	$4\frac{3}{16}$	$4\frac{15}{16}$	5	$5\frac{11}{16}$	$5\frac{15}{16}$	$6\frac{13}{16}$	$7\frac{9}{16}$	$8\frac{1}{4}$	$10\frac{1}{8}$
f	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{7}{8}$	1	1	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{2}$
g	$5\frac{5}{16}$	$5\frac{15}{16}$	$6\frac{9}{16}$	$7\frac{11}{16}$	$8\frac{1}{2}$	$9\frac{9}{16}$	$10\frac{1}{4}$	$11\frac{3}{8}$	$12\frac{1}{8}$	$13\frac{1}{16}$	$14\frac{5}{8}$	$16\frac{5}{8}$	$18\frac{1}{4}$	$21\frac{1}{4}$	$28\frac{3}{8}$

Pedestals, or Plummer-blocks.

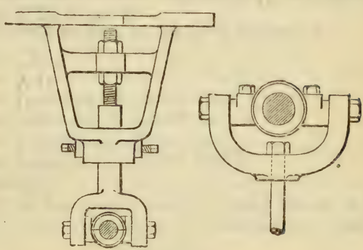
Diameter of neck .. .. = D.
Thickness of cover .. .. = $D \times \cdot 4$.
Thickness of sole-plate .. = $D \times \cdot 3$.
Diameter of bolts .. .. = $D \times \cdot 25$, if 2 bolts.
Ditto .. .. = $D \times \cdot 18$, if 4 bolts.

Steps, or Brasses of Plummer-blocks.

D = Diameter of bearing in inches.
T = Thickness of metal at bottom in inches.
t = Thickness of metal at sides.
$T = D \times 0 \cdot 12 + 0 \cdot 15$.
$t = 0 \cdot 75\ T$, or $\frac{3}{4}\ T$.

Note.—The results of this formula agree very closely with the London practice. In the North lighter brasses are used, and the formula $T = D \times \cdot 09 + \cdot 15$ would agree more nearly with the Northern practice.

Adjustable Bearings for Shafting. (J. Richards.)



Pulleys.

Convexity of pulleys to receive the strap = $\frac{1}{8}$ to $\frac{1}{16}$ in. per foot of width in high speeds = $\frac{1}{4}$ in low speeds.

V = Velocity of driving pulley.
v = Velocity of driven ditto.
D = Diameter of driving pulley.
d = Diameter of driven ditto.

$$v = \frac{V\,D}{d}.$$

In a train of pulleys the final velocity = $\frac{V \times D \times D' \times D'', \&c.}{d \times d' \times d'', \&c.}$, where D' D'' are the diameters of the driving pulleys, and d' d'' those of the driven.

Leather Belting.

V = Velocity of belt in feet per minute.
HP = Horse-power (actual) transmitted by belt.
S = Strain on belting in lbs.
W = Width of single belting ($\frac{3}{16}$ thick) in inches.

$S = x + k\,x$. $W = \cdot 02\,S$.

$$x = \frac{33000\ HP}{V}.$$

$k = 1\cdot 1$ when portion of driven pulley embraced by belt = $\cdot 40$ circumference.

$k = \cdot 77$ when portion of driven pulley embraced by belt = $\cdot 50$ circumference.

$k = \cdot 62$ when portion of driven pulley embraced by belt = $\cdot 60$ circumference.

For double belting the width = $W \times 0\cdot 6$.

Approximate rule for single belting, $\frac{3}{16}$ thick,

$$W = \frac{1100\ HP}{V}.$$

High-speed Belting.

The formulæ above apply to ordinary cases, but are inapplicable to cases in which very small pulleys are driven at very high velocities; as in some wood-cutting machines, fans, &c., the acting area of the belt on the circumference of the driven pulley being so small that either great tension or a greater breadth than that determined by the formula is required to prevent the belt from slipping.

In such extreme cases of high-speed belts, find the breadth of the first-motion belt (the belt which imparts motion to the driving pulley) by the formula for ordinary belting, $W = \frac{1100\ HP}{V}$;

then, if

A = Acting area of first-motion belt,
v = Velocity of first-motion belt,
a = Acting area of high-speed belt,
V = Velocity of high-speed belt,

$$a = \frac{A\,v}{V}.$$

The acting area of either belt $= l \times o$.

Where l = length of circumference of driven pulley embraced by the belt,
b = breadth of belt,

$\therefore\ b = \frac{a}{l}$ in the case of the high-speed belt.

If there is no first-motion belt exclusively for the machine, it will be easy to suppose a hypothetical case, from which the breadth of the high-speed belt may be calculated.

Long belts are more effective than short belts.

Hemp Rope Gearing.

(Durie, 'Trans. Inst. Mech. Eng.,' 1876.)

Ropes $5\frac{1}{4}$ to $6\frac{1}{2}$ circumference; $4\frac{1}{4}$ for small power.

Velocity of rope from 3000 to 6000 feet per minute.

Circumference of pulley not less than 30 times the circumference of the rope. A good proportion for the diameter of the driving pulley first motion is **100** times the diameter of the rope; second motion, 50 times.

The distance of the two pulleys apart, from 30 to 60 feet.

The ropes should not rest on the bottom of the groove, which should be V-shaped, the sides being at an angle of 40°.

The length of the splice should be about 15 times the circumference of the rope.

The rope should never be strained so as to draw it to a near approach to straight, even in short spans.

Weight of ropes in lbs. per foot $= \cdot 04\ C^2$.

Working tension of the rope from 110 to 120 lbs. per square inch of its section.

Formula for Hemp Rope Gearing.

$V =$ Velocity of rope in feet per minute.
$n =$ Number of ropes.
$C =$ Circumference of rope in inches.
$P =$ Indicated horse-power.

$$P = \frac{C^2\ V\ (n-1)}{4000}.$$

$$C = \sqrt{\frac{4000\ P}{V\ (n-1)}}.$$

This formula is under the supposition that the number of ropes is one in excess of the number actually required, so as to provide for changing and repairs.

Some ropes have run for $10\frac{1}{2}$ years, but as a rule the life of a rope is from 3 to 5 years.

TRANSMISSION OF POWER BY WIRE ROPE. (Roebling.)

1. Power may be transmitted economically by round endless wire ropes to a distance of 3 miles.

2. Wire rope transmission costs $\frac{1}{15}$th the amount of belting, and $\frac{1}{25}$th that of shafting.

3. The range of rope is from $\frac{3}{8}$ to $\frac{7}{8}$ inch diameter.

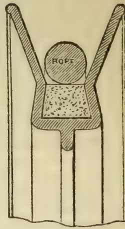
4. The ropes should be made with a hempen core to increase pliability.

5. It is not necessary that the two wheels should be at the same height.

6. The deflection of the lower rope when working is one-half greater than the rope at rest, or about $\frac{1}{25}$th of the distance from wheel to wheel.

7. The lower rope should be made the pulling rope.

8. The groove in the wheels should be formed as shown in the accompanying diagram, the wire rope resting on a filling of either soft wood, india-rubber, or oakum. The recess should be dovetailed to prevent the filling from coming out.



SECTION OF PERIPHERY OF DRIVING PULLEY.

9. A little hot coal-tar occasionally poured into the groove is a good lubricant.

TRANSMISSION OF POWER BY WIRE ROPE.

D = Diameter of pulley in feet.
R = Revolutions of ditto per minute.
d = Diameter of rope in inches. HP = Horse-power.

D	4				5				6			
R	80	100	120	140	80	100	120	140	80	100	120	140
d	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{7}{16}$	$\frac{7}{16}$	$\frac{7}{16}$	$\frac{15}{32}$	$\frac{15}{32}$	$\frac{15}{32}$	$\frac{15}{32}$
HP	3·3	4·1	5	5·8	6·9	8·6	10·3	12·1	10·7	13·4	16·1	18·7

D	7				8				9			
R	80	100	120	140	80	100	120	140	80	100	120	140
d	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$
HP	16·9	21·1	25·3	29·6	22	27·5	33	38·5	41·5	51·9	62·2	72·6

D	10			12			14		15	
R	100	120	140	100	120	140	100	120	100	120
d	$\frac{11}{16}$	$\frac{11}{16}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$
HP	73	87·6	102·2	124·1	148·9	173·7	176	211	259	300

Screws.

Angle of thread = 55°.

$\frac{1}{6}$ of depth is rounded off at top and bottom.

Number of threads to the inch in square threads = $\frac{1}{2}$ number of those in angular threads.

Depth of threads = ·64 pitch for angular, = ·475 pitch for square threads.

Whitworth's Standard Nuts and Bolt-heads.

Diam. of Bolt, inches.	Width across Flats.	Thickness of Nuts.	Thickness of Bolt-heads.	Diam. of Bolt at Bottom of Thread.	Diam. of Bolt, inches.	Width across Flats.	Thickness of Nuts.	Thickness of Bolt-heads.	Diam. of Bolt at Bottom of Thread.
$\frac{1}{8}$	·338	$\frac{1}{8}$	·1093	·0929	$1\frac{1}{8}$	1·8605	$1\frac{1}{8}$	·9843	·942
$\frac{3}{16}$	·448	$\frac{3}{16}$	·1640	·1341	$1\frac{1}{4}$	2·0483	$1\frac{1}{4}$	1·0937	1·067
$\frac{1}{4}$	·525	$\frac{1}{4}$	·2187	·1859	$1\frac{3}{8}$	2·2146	$1\frac{3}{8}$	1·2031	1·1615
$\frac{5}{16}$	·6014	$\frac{5}{16}$	·2734	·2413	$1\frac{1}{2}$	2·4134	$1\frac{1}{2}$	1·3125	1·2865
$\frac{3}{8}$	·7094	$\frac{3}{8}$	·3281	·2949	$1\frac{5}{8}$	2·5763	$1\frac{5}{8}$	1·4218	1·3688
$\frac{7}{16}$	·8204	$\frac{7}{16}$	·3828	·346	$1\frac{3}{4}$	2·7578	$1\frac{3}{4}$	1·5312	1·4938
$\frac{1}{2}$	·9191	$\frac{1}{2}$	·4375	·3932	$1\frac{7}{8}$	3·0183	$1\frac{7}{8}$	1·6406	1·5904
$\frac{9}{16}$	1·011	$\frac{9}{16}$	·4921	·4557	2	3·1491	2	1·75	1·7154
$\frac{5}{8}$	1·101	$\frac{5}{8}$	·5468	·5085	$2\frac{1}{8}$	3·337	$2\frac{1}{8}$	1·8593	1·8404
$\frac{11}{16}$	1·201	$\frac{11}{16}$	·6015	·571	$2\frac{1}{4}$	3·546	$2\frac{1}{4}$	1·9687	1·9298
$\frac{3}{4}$	1·3012	$\frac{3}{4}$	·6562	·6219	$2\frac{3}{8}$	3·75	$2\frac{3}{8}$	2·0781	2·0548
$\frac{13}{16}$	1·39	$\frac{13}{16}$	·7109	·6844	$2\frac{1}{2}$	3·894	$2\frac{1}{2}$	2·1875	2·1798
$\frac{7}{8}$	1·4788	$\frac{7}{8}$	·7656	·7327	$2\frac{5}{8}$	4·049	$2\frac{5}{8}$	2·2968	2·3048
$\frac{15}{16}$	1·5745	$\frac{15}{16}$	·8203	·7952	$2\frac{3}{4}$	4·181	$2\frac{3}{4}$	2·4062	2·384
1	1·6701	1	·875	·8399	3	4·531	3	2·625	2·634

Whitworth's Standard Gauges, deposited at the Standards Department, Board of Trade.

	Decimal.				Fractional.		
Range from, inches ..	·01 to ·1	·1 to 1	1·1 to 4	4·2 to 6	$\frac{1}{8}$ to 1	$1\frac{1}{8}$ to 4	$4\frac{1}{4}$ to 6
Rate of increase per gauge ..	·001 in.	·05	·1	·2	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{1}{4}$
No. of gauges per set ..	91	19	30	10	15	24	8

WHITWORTH'S STANDARD FOR SCREWS WITH ANGULAR THREADS.

No. of Threads per inch.	Old Sizes, inches.	New Standard, decimals of an inch.	No. of Threads per inch.	Old Sizes, inches.	New Standard, decimals of an inch.	No. of Threads per inch.	Old Sizes, inches.	New Standard, decimals of an inch.
48		·100	12		·600	4	$2\frac{3}{8}$	2·375
40	$\frac{1}{8}$	·125	11	$\frac{5}{8}$	·625	4	$2\frac{1}{2}$	2·500
32		·150	11		·650	4	$2\frac{5}{8}$	2·625
24		·175	11		·675	$3\frac{1}{2}$	$2\frac{3}{4}$	2·750
24		·200	11		·700	$3\frac{1}{2}$	$2\frac{7}{8}$	2·875
24		·225	10	$\frac{3}{4}$	·750	$3\frac{1}{2}$	3	3·000
20	$\frac{1}{4}$	·250	10		·800	$3\frac{1}{4}$	$3\frac{1}{4}$	3·25
20		·275	9	$\frac{7}{8}$	·875	$3\frac{1}{4}$	$3\frac{1}{2}$	3·50
18		·300	9		·900	3	$3\frac{3}{4}$	3·75
18		·325	8	1	1·000	3	4	4·00
18		·350	7	$1\frac{1}{8}$	1·125	$2\frac{7}{8}$	$4\frac{1}{4}$	4·25
16	$\frac{3}{8}$	·375	7	$1\frac{1}{4}$	1·250	$2\frac{7}{8}$	$4\frac{1}{2}$	4·50
16		·400	6	$1\frac{3}{8}$	1·375	$2\frac{3}{4}$	$4\frac{3}{4}$	4·75
14		·425	6	$1\frac{1}{2}$	1·500	$2\frac{3}{4}$	5	5·00
14		·450	5	$1\frac{5}{8}$	1·625	$2\frac{5}{8}$	$5\frac{1}{4}$	5·25
14		·475	5	$1\frac{3}{4}$	1·750	$2\frac{5}{8}$	$5\frac{1}{2}$	5·50
12	$\frac{1}{2}$	·500	$4\frac{1}{2}$	$1\frac{7}{8}$	1·875	$2\frac{1}{2}$	$5\frac{3}{4}$	5·75
12		·525	$4\frac{1}{2}$	2	2·000	$2\frac{1}{2}$	6	6·00
12		·550	$4\frac{1}{2}$	$2\frac{1}{8}$	2·125			
12		·575	4	$2\frac{1}{4}$	2·250			

WHITWORTH'S GAS THREADS.

Diameter in inches	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2
No. of Threads per inch	28	19	19	14	14	11	11	11	11	11

WHITWORTH'S STANDARD WATCH AND MATHEMATICAL INSTRUMENT SCREWS.

Diam. from in. to "	·010 ·014	·015 ·019	·020 ·024	·026 ·030	·032 ·038	·040 ·055	·060 ·075	·080 ·095	·10
Threads per in.	250	210	180	150	120	100	80	60	50

Friction of Plane Surfaces.

Mean Coefficient of Friction of Repose.

Surfaces.	Nature of Unguent.						
	Dry.	Damp with Water.	Olive Oil.	Lard.	Tallow.	Dry Soap.	Polished and Greasy.
Wood on wood	·50	·68	—	·21	·19	·36	·35
Metal on metal	·18	—	·12	·10	·11	—	·15
Wood on metal	·60	·65	·10	·12	·12	—	·10
Matted hemp on wood ..	·63	·87	—	—	—	—	—
Sole leather on wood or iron	·62	·80	·13	—	—	—	—
Belting on iron pulleys ..	·54	—	—	—	—	—	—
Belting on wood " ..	·47	—	—	—	—	—	·28
Stones on stones or bricks	·71	—	—	—	—	—	—
Stones on wrought iron ..	·45	—	—	—	—	—	—
Wood on stones	·60	—	—	—	—	—	—

The coefficient of friction of motion in most cases = the coefficient of repose × 0·7; coefficient × pressure = power required to overcome the friction.

Rule for finding the Weight of Castings or Forgings by the Weight of their Patterns.

Weight of pattern in well-dried pine .. × 16 = cast iron.
" " × 17·1 = wrought iron.
" " × 17·6 = steel.
" " × 19 = copper.
" " × 25 = lead.

Friction of Plane Surfaces. ('Trans. Inst. C. E.,' liii.)

Kimball reports that whilst the coefficient of friction as the velocity increases beyond the limit due to the maximum coefficient, it decreases towards a constant value. The coefficient also slightly decreases with the pressure.

Coefficients with $\frac{7}{8}$-inch shafting on cast-iron bearings:—

Velocity, feet per minute	1	3	5	7	10	15	20	30	40	60	80	100
Coefficient per cent.	15·	12·2	10·4	9·3	7·9	6·6	5·8	5·4	5·3	5·2	5·1	5·

With pressures from $23\frac{1}{2}$ lbs. to $196\frac{1}{4}$ lbs. per square inch of longitudinal section of journal, the coefficient at very low speed decreased by from 6 to 11 per cent.

For the greatest pressures the coefficient appears to become stationary.

From experiments by Poirée and Bochet on waggon friction on rails, the coefficients from 900 to 4000 feet per minute decrease from ·21 to ·14 respectively.

Frictional Resistance of Pneumatic Foundations. (Schmoll.)

The tube or caisson must be vertical and free, neither resting on the guide chains or on its lower edge, but only kept in equilibrium by the friction of its surface.

Table of Coefficients of Friction.		Dry Material.		Wet Material.	
Material.	Soil.	First Movement.	During Motion.	First Movement.	During Motion.
Sheet iron without rivets	Gravel and sand	·4015	·4583	·3348	·4409
„ with rivets ..	„ „	·3965	·4911	·4677	·5481
Cast iron unplaned ..	„ „	·3677	·4668	·3646	·4963
Granite roughly worked	„ „	·4266	·5368	·4104	·4800
Pine, sawn	„ „	·4088	·5109	·4106	·4985
Sheet iron without rivets	Sand	·5361	·6313	·3655	·3247
„ with rivets ..	„	·7269	·8391	·5156	·4977
Cast iron unplaned ..	„	·5636	·6063	·4744	·3796
Granite roughly worked	„	·6473	·7000	·4728	·5291
Pine, sawn	„	·6633	·7340	·5787	·4793

Contrary to Morin's experience, the friction from rest is smaller than the resistance during motion.

Alloys.

Alloys.	Tin.	Copper.	Zinc.	Antimony.	Lead.	Bismuth.
Brass, engine bearings	13	112	¼	—	—	—
Tough brass, engine work ..	15	100	15	—	—	—
„ for heavy bearings	25	160	5	—	—	—
Yellow brass, for turning ..	—	2	1	—	—	—
Flanges to stand brazing ..	—	32	1	—	1	—
Bell-metal	5	16	—	—	—	—
Babbitt's metal	10	1	—	1	—	—
Brass, for locomotive bearings	7	64	1	—	—	—
„ for straps and glands ..	16	130	1	—	—	—
Muntz's sheathing	—	6	4	—	—	—
Metal to expand in cooling ..	—	—	—	2	9	1
Pewter	100	—	—	17	—	—
Spelter	—	1	1	—	—	—
Statuary bronze	2	90	5	—	2	—
Type-metal .. .. from	—	—	—	1	3	—
„ .. .. to	—	—	—	1	7	—
Solders.						
For lead	1	—	—	—	1½	—
„ tin	1	—	—	—	2	—
„ pewter	2	—	—	—	1	—
„ brazing (hardest)	—	3	1	—	—	—
„ „ (hard)	—	1	1	—	—	—
„ „ (soft)	1	4	3	—	—	—
„ „ „ .. .. or	2	—	—	1	—	—

Fluxes for Soldering or Welding.

Iron or steel	Borax or sal-ammoniac.
Tinned iron	Resin or chloride of zinc.
Copper and brass ..	Sal-ammoniac or chloride of zinc.
Zinc	Chloride of zinc.
Lead	Tallow or resin.
Lead and tin pipes	Resin and sweet oil.

Tempering Steel.

Colour.	Purpose.	Temperature.	Alloy whose Fusing Point is of the same Temperature.	
		Fah.	tin.	lead.
Light straw	Turning tools for metal	430°	1 to	1¾
Dark straw .	Wood tools, taps, and dies ..	470°	1 „	2½
Brown yellow	Hatchets, chipping chisels ..	500°	1 „	4¼
Dark purple	Springs, &c. ..	550°	1 „	12

Brazing.

The edges filed or scraped clean and bright, covered with spelter and powdered borax and exposed in a clear fire to a heat sufficient to melt the solder.

To Test Steel and Iron. ('Scientific American.')

Nitric acid will produce a black spot on steel; the darker the spot the harder the steel. Iron, on the contrary, remains bright if touched with nitric acid.

Good steel in its soft state has a curved fracture and a uniform grey lustre; in its hard state a dull, silvery, uniform white. Cracks, threads, or sparkling particles denote bad quality.

Good steel will not bear a white heat without falling to pieces, and will crumble under the hammer at a *bright* red heat, while at a middling heat it may be drawn out under the hammer to a fine point.

Care should be taken that before attempting to draw it out to a point the fracture is not concave, and should it be so the end should be filed to an obtuse point before operating. Steel should be drawn out to a fine point and plunged into cold water; the frac-

tured point should scratch glass. To test its toughness, place a fragment on a block of cast iron; if good it may be driven by the blow of a hammer into the cast iron, if poor it will crush under the blow.

Tests of Iron.

A soft, tough iron, if broken gradually, gives long silky fibres of leaden-grey hue, which twist together and cohere before breaking.

A medium even grain with fibres denotes good iron.

Badly-refined iron gives a short blackish fibre on fracture. A very fine grain denotes hard steely iron, likely to be cold-short, and hard.

Coarse grain with bright crystallized fracture or discoloured spots denotes cold-short, brittle iron, which works easily when heated and welds well. Cracks on the edge of a bar are indications of hot-short iron. Good iron is readily heated, is soft under the hammer, and throws out few sparks.

WORKSHOP RECIPES.

Antifriction Grease.

Boil together, $1\frac{3}{4}$ cwt. of tallow with $1\frac{1}{4}$ cwt. of palm oil. When boiling point is reached allow it to cool to blood heat, stirring it meanwhile, then strain through a sieve into a solution of $\frac{1}{2}$ cwt. of soda in 3 gallons of water, mixing it well.

The above is for summer.

For winter, $1\frac{1}{4}$ cwt. of tallow to $1\frac{3}{4}$ cwt. palm oil.
Spring and autumn, $1\frac{1}{2}$ „ $1\frac{1}{2}$ „

Foundry Recipes.

Fire-clay crucibles, 2 Stourbridge clay,
1 hard gas-coke, finely powdered.

Berlin crucibles, 8 Stourbridge clay,
3 old crucibles, ground finely,
5 coke,
4 graphite, or "black-lead."

Black-lead crucibles, 1 fire-clay,
2 graphite.

Workshop Recipes—*continued.*

PARTING SAND.

Burnt sand scraped from the surface of castings.

LOAM.

Mixture of brick, clay, and old foundry sand.

BLACKENING FOR MOULDS.

Charcoal powder; or, in some instances, fine coal-dust.

BLACK WASH.

Charcoal, plumbago, and size.

MIXTURE FOR WELDING STEEL.

1 sal-ammoniac,
10 borax,

Pounded together, and fused until clear, when it is poured out, and, after cooling, reduced to powder.

Rust-joint Cement (*Quickly Setting*).

1 sal-ammoniac in powder (by weight).
2 flour of sulphur.
80 iron borings made to a paste with water.

Rust-joint (*Slowly Setting*).

2 sal-ammoniac.
1 flour of sulphur.
200 iron borings.

The latter cement is the best if the joint is not required for immediate use.

Red-lead Cement for Face-joints.

1 of white-lead.
1 of red-lead, mixed with linseed oil to the proper consistency.

Workshop Recipes—*continued.*

Case-hardening.

Place horn, hoof, bone-dust, or shreds of leather, together with the article to be case-hardened, in an iron box subject to a blood-red heat, then immerse the article in cold water.

Some engineers cut up the shreds, &c., fine, and mix them with white wine vinegar, and salt.

Case-hardening with prussiate of potash.

Heat the articles after polishing to a bright red, rub the surface over with prussiate of potash; allow it to cool to dull red, and immerse it in water.

Case-hardening mixtures.

3 prussiate of potash to 1 of sal-ammoniac mixed, or 2 sal-ammoniac, 2 of bone-dust, and 1 of prussiate of potash.

Glue to Resist Moisture.

1 lb. of glue melted in 2 quarts of skimmed milk.

When strong glue is required add powdered chalk to common glue.

Marine Glue.

1 of india-rubber, 12 of mineral naphtha or coal-tar, heat gently, mix, and add 20 of powdered shellac. Pour out on a slab to cool—when used to be heated to about 250°.

Glue Cement to Resist Moisture.

$\left.\begin{array}{l}\text{1 glue}\\ \text{1 black rosin}\\ \tfrac{1}{4}\text{ red ochre}\end{array}\right\}$ mixed with the least possible quantity of water.

OR,

4 of glue.
1 of boiled oil by weight.
1 oxide of iron.

Workshop Recipes—*continued.*

Galvanizing Iron.

1. Pickle the article six or eight hours in water containing about 1 per cent. of sulphuric acid held in wooden vessels; the acid requires to be renewed from time to time, according to the quantity of iron pickled.

2. After pickling scour and wash well in clean water.

3. Keep the article under clean water (in which a little fresh burnt lime has been stirred) until ready for the next process.

4. Immerse in chloride of zinc for one or two minutes until a skin of fine bubbles is formed on the surface. Chloride of zinc may be formed by saturating hydrochloric acid with metallic zinc until effervescence ceases, then decanting and adding a little sal-ammoniac.

5. Dry the article on a heated iron plate, then immerse it in a bath of molten (not glowing) zinc until it acquires the temperature of the zinc bath. The surface of the molten zinc should be protected by sal-ammoniac or some other substance. In some cases there is a partition at the surface of the bath, one portion of the surface being protected with sal-ammoniac, the other with a layer of charcoal.

6. Beat the article while hot, to remove the excess of zinc.

Workshop Recipes—*continued.*

Dubbing.

2 lbs. black resin. 1 lb. tallow. 1 gallon train oil.

Cement for Cloth or Leather.

16 gutta-percha cut small
4 india-rubber „
2 pitch „
1 shellac „
2 linseed oil „
} melted together and well mixed.

Iron Lacquer.

12 of amber. 12 of turpentine. 2 of resin. 2 of asphaltum. 6 of drying oil.	or	3 lbs. of asphaltum. $\frac{1}{2}$ lb. of shellac. 1 gallon of turpentine.

Brass Lacquer.

8 ounces of shellac. 2 ounces of sandarach. 2 ounces of annatto. $\frac{1}{4}$ ounce of dragon's blood resin. 1 gallon of spirits of wine.	or	8 ounces of shellac. 1 gallon of spirits of wine.

The article to be lacquered should be heated slightly, and the lacquer should be applied by means of a soft camel's-hair brush.

Whiting.

Chalk reduced to a fine powder by levigation.

Staining Wood.

Mahogany colour ..	Burnt sienna ground in vinegar.
Walnut „ ..	Dissolve in hot water 1 of soda with $1\frac{1}{4}$ vandyke brown and $\frac{1}{8}$th bichromate of potash.
Red stain	Dissolve dragon's blood in spirits of wine.
Black stain	Dissolve permanganate of potash in water.

French Polish.

3 ounces of shellac dissolved cold in a pint of spirits of wine; if desired, it may be darkened with "dragon's blood."

Dark Drying Oil (for Paint).

1 gallon linseed oil.
1 lb. of red-lead.
1 lb. of umber.
1 lb. of litharge.

The linseed oil is heated to about 200° Fahr. and the scum removed. The red-lead, umber, and litharge are then added, and the whole raised to 400° Fahr., and kept at that heat about 3 hours. It is then allowed to settle before decanting off.

Raw Drying Oil.

Add white-lead in the proportion of 1 lb. of lead to 1 gallon of linseed oil; then allow it to settle for a week.

Copal Varnish.

Fuse 8 lbs. of African gum copal; add 2 gallons of clarified oil. Boil very slowly for 4 or 5 hours until quite stringy, and mix with $3\frac{1}{2}$ gallons of turpentine.

White Hard Spirit Varnish.

Dissolve $3\frac{1}{4}$ lbs. gum sandarach in 1 gallon of spirits of wine; when dissolved add 1 pint of turpentine. For brown varnish substitute shellac for sandarach.

Black Varnish.

Fuse 3 lbs. of Egyptian asphaltum, and when liquid add $\frac{1}{4}$ lb. of shellac and 1 gallon of turpentine.

Turpentine Varnish.

$\frac{1}{4}$ lb. of resin dissolved in a pint of oil of turpentine warm.

Crystal Varnish for Tracing Paper.

Canada balsam dissolved in oil of turpentine in equal quantities.

Driers.

Litharge or oxide of lead; red-lead and sulphate of zinc are also used. Oxide of manganese is used for quick drying. From $\frac{1}{4}$ to 1 lb. of driers are used to a gallon of oil. Resin is sometimes mixed with paint to make it dry.

Painting Old Work.

Old paint should be washed with soap and water or a solution of pearlash, and afterwards rubbed with pumice-stone. To remove old paint, dissolve 1 ounce of soft soap and 2 ounces potash in boiling water, and add 4 ounces of quicklime. Apply hot, and leave it on for 12 or 15 hours.

Workshop Recipes—*continued.*

Painting.

A gallon of mixture, or 6 pints of raw linseed oil, 1 pint of boiled oil, 1 pint of turpentine, requires from 12 to 14 lbs of dry paint.

These proportions vary according to circumstances.

A Gallon will cover	Superficial yds.	Superficial feet.
On stone or brick, about	25 to 30	225 to 270
On compo, &c. .. .. from	40	360
" .. .. .. to	50	450
On wood .. .. .. from	50	450
" .. .. .. to	70	630
On well-painted surface or iron	80	720
One gallon tar, first coat.. ..	12	108
" " second coat ..	16	144

Priming.—White-lead (sometimes mixed with chalk) diluted with linseed oil.

Knotting.—Red-lead and size.

Putty.—Spanish whiting and linseed oil well beaten and kneaded into a stiff paste.

Proportions of Colours for Ordinary Paints.

Colours.	Ingredients by Weight.						
	White-lead.	Lamp-black.	Red-lead.	Red Ochre.	Verdi-gris.	Burnt Umber.	Spanish Brown
White	100	—	—	—	—	—	—
Black.. ..	—	100	—	—	—	—	—
Green	25	—	—	—	75	—	—
Stone.. ..	99	—	—	—	—	1	—
Lead	98	2	—	—	—	—	—
Red	—	—	50	50	—	—	—
Chocolate ..	—	4	—	—	—	—	96

QUANTITY OF WHITE PAINT REQUIRED TO COVER 100 SQUARE YARDS OF NEW WROUGHT DEAL.

("Building Construction.")

	Red-lead.	White-lead.	Raw Linseed Oil.	Boiled Linseed Oil.	Turpentine.	Driers.
	lbs.	lbs.	pints.	pints.	pints	lbs.
Inside work not flatted—						
Priming*	½	16	6	—	—	¼
Second coat	†	15	3¼	—	1½	¼
Third "	—	13	2½	—	1½	¼
Fourth "	—	13	2¼	—	1½	¼
Inside work flatted—						
Priming	1½	16	6	—	½	⅛
Second coat	—	12	4	—	1½	$\frac{1}{10}$
Third "	—	12	4	—	—	$\frac{1}{10}$
Fourth "	—	12	4	—	—	$\frac{1}{10}$
Flatting	—	9	—	—	3½	$\frac{1}{10}$
Outside work ‡—						
Priming	2	18½	2	2	—	⅛
Second coat	—	15	2	2	½	$\frac{1}{10}$
Third "	—	15	2	2	½	$\frac{1}{10}$
Fourth "	—	15	3	2½	—	$\frac{1}{10}$

For every 100 square yards, besides the materials enumerated above, 2 lbs. of white-lead and 5 lbs. of putty will be required for stopping.

* Sometimes more red-lead is used and less drier.

† Sometimes just enough red-lead to give a flesh-coloured tint.

‡ When the finished colour is not to be pure white, it is better to have nearly all the oil boiled oil. All boiled oil does not work well. For pure white a larger proportion of raw oil is necessary, because boiled oil is too dark.

WORKSHOP RECIPES—*continued.*

INCRUSTATION OF BOILERS.

Remedies that have been adopted with more or less success for boiler incrustation. ('Mechanics' Magazine.')

1. Potatoes, $\frac{1}{50}$th of weight of water, prevent adherence of scale.

2. 12 parts salt, $2\frac{1}{2}$ caustic soda, $\frac{1}{8}$th extract of oak-bark, $\frac{1}{2}$ of potash.

3. Pieces of oak-wood, suspended in boiler and renewed monthly, prevent deposit.

4. 2 ounces of muriate of ammonia in boiler twice a week, prevents incrustation and decomposes scale.

5. Coating of 3 parts black-lead, 18 tallow, applied hot to the inside of a boiler every few weeks, prevents scale.

6. 13 lbs. of molasses fed occasionally into an 8-horse boiler prevented incrustation for six months.

7. Mahogany or oak sawdust in limited quantities. The tannic acid attacks the iron, and should therefore be used with caution.

8. Slippery elm-bark has been used with some success.

9. Carbonate of soda. 10. Chloride of tin.

11. Spent tanners' bark.

12. Frequent blowing off.

Paraffin oil has been used with excellent results in locomotive boilers.

Marine boilers are sometimes protected from corrosion by a thin wash of Portland cement inside.

Ferrotype (or Blue) Process.

By this process prints are produced in prussian blue and white, a print taken direct from an ordinary tracing in indian ink giving white lines on a blue ground.

SENSITIZING SOLUTION.

A	Citrate of iron and ammonia	100 grains.
	Water	1 ounce.
B	Red prussiate of potash	70 grains.
	Water	1 ounce.

These solutions will keep indefinitely before mixing, but, when mixed, they should be used at once or left in the dark.

PREPARING THE PAPER.

Mix equal quantities of A and B and apply to one side of the paper with a sponge. The sponge should be as full as it will hold of the solution, which should be liberally applied to the paper for about two minutes. Then squeeze out the sponge and wipe off all the solution from the surface of the paper, care being taken to use the sponge *lightly without* abrading the surface. The paper, which is now of a bright yellow colour on the prepared side, should be hung up to dry in the dark.

PRINTING.

The printing is done in every respect in the same manner as for ordinary photographic silver prints, the tracing representing the negative.

Behind the glass of the printing frame lay the tracing, face next the glass, behind the tracing the prepared paper, prepared surface next the tracing. Put out in the sun or diffused daylight until sufficiently printed.

In bright sun-light from 9 A.M. to noon the time required will be from 8 to 10 minutes. In the afternoon a somewhat longer exposure must be given.

FIXING.

The print is fixed by simply washing thoroughly in clean water.

ADDITIONS AND ERASURES.

A white line may be taken out by going over it with a quill pen or brush dipped in the sensitizing solution, exposing to the sun, and washing as before. Additions or corrections in white may be made with a quill pen dipped in a solution of 40 grains of carbonate of potash to 1 ounce of water. After using this solution, the potash must be dried with blotting paper and washed, or the lines will spread and become blurred.

Power required to Punch Boiler-plates, &c.

P = Power required in tons.
T = Thickness of iron in inches.
D = Diameter of hole in inches.
$P = 80\ D\ T$.

Punching copper requires a force of about $\frac{2}{3}$ that required for iron.

Dynamometer.

To estimate the horse-power as indicated by the dynamometer:—

L = Length of lever in feet.
N = Number of revolutions of shaft per minute.
W = Weight applied to the end of the lever in lbs., including the weight of the scale.

Actual horse-power $= \cdot 0001904\ W\ L\ N$.

Dredging Machines.

Depth of Water. Feet.	Number of Buckets.	Length of Bucket Ladder. Feet.	Nominal Horse-power.
18	34	60	20
20	36	63	25
25	45	78	30

C = No. of cube feet excavated per minute.
H = Height to which the earth is to be raised.
P = Actual horse-power required.

$P = C(\cdot 004\ H + \cdot 35)$ for stiff clay and gravel.
$\ \ = C(\cdot 004\ H + \cdot 15)$ for soft clay and mud.

Depreciation of Machinery, &c., per Annum on First Cost.

	Depreciation.	Wear and Tear.	Total.
Engines	3 per cent.	3 per cent.	6 per cent.
Boilers	7 „	3 „	10 „
Machines	5 „	3 „	8 „
Millwork and gearing	3 „	2½ „	5½ „
Bands and belts ..	—	45 „	45 „

Shrinkage of Castings.

In locomotive cylinders	= $\frac{1}{16}$ inch in a foot.
In pipes	= $\frac{1}{8}$,, ,,
Girders, beams, &c.	= $\frac{1}{8}$ in 15 inches.
Engine-beams, connecting rods	= $\frac{1}{8}$ in 16 ,,
In large cylinders, say 70-inch diameter, 10-feet stroke, the contraction of diameter.. ..	= $\frac{3}{8}$ at top.
Ditto	= $\frac{1}{2}$ at bottom.
Ditto, in length	= $\frac{1}{8}$ in 16 inches.
In thin brass	= $\frac{1}{8}$ in 9 ,,
In thick brass	= $\frac{1}{8}$ in 10 ,,
In zinc	= $\frac{5}{16}$ in a foot.
In lead	= $\frac{5}{16}$,,
In copper	= $\frac{3}{16}$,,
Bismuth	= $\frac{5}{32}$,,
Tin..	= $\frac{1}{4}$,,

Rule for Change Wheels in Screw-cutting Lathes.

N = No. of threads per inch to be cut.
P = No. of threads per inch on traverse screw.
S = No. of teeth in wheel on mandrel.
W = No. of teeth in stud wheel (gearing in S).
Y = No. of teeth in stud pinion (gearing in T).
T = No. of teeth in wheel on traverse screw.

$$N = P\frac{TW}{SY}. \qquad W = N\frac{SY}{PT}.$$

Weight of Leather Belting, Lbs. per Foot Run.

Breadth, ins.	$1\frac{3}{4}$	2	$2\frac{1}{2}$	3	$3\frac{1}{2}$	4	$4\frac{1}{2}$	5	$5\frac{1}{2}$
Single, lbs...	·20	·23	·29	·35	·40	·46	·52	·58	·63
Double, ,, ..	·40	·46	·58	·69	·81	·92	1·04	1·15	1·27
Breadth, ins.	6	$6\frac{1}{2}$	7	$7\frac{1}{2}$	8	9	10	11	12
Single, lbs...	·69	·75	·81	·86	·92	1·04	1·15	1·27	1·38
Double, ,, ..	1·38	1·50	1·61	1·72	1·84	2·07	2·30	2·53	2·76

Cranes.

Ordinary height of handle above ground, 3 feet.
Diameter of circle described by handle, 32 inches.
Angle of jib = 45°.

Each man working at the handle of a crane imparts a pressure of about 15 to 20 lbs.

W = Weight to be raised by crane in lbs.
P = Power applied to the handle in lbs.
D = Diameter of circle described by handle in inches.
n = Number of revolutions of handle to one of barrel.
B = Diameter of barrel in inches.

$$B = \frac{D \times P \times n}{W}. \qquad D = \frac{W \times B}{P \times n}.$$

$$n = \frac{W \times B}{D \times P}. \qquad P = \frac{W \times B}{n \times D}.$$

$$W = \frac{P \times D \times n}{B}.$$

Power gained by Blocks.

Let N = number of cords or chains leading to or from the movable block, the power gained will = N.

Stiffness of Ropes.

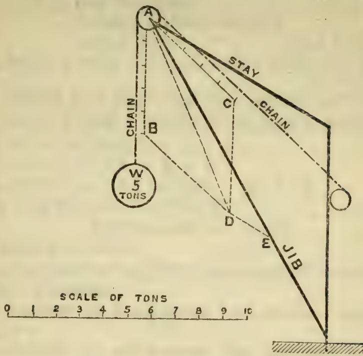
R = Stiffness of ropes in lbs. avoirdupois, or excess of tension at the leading side of the rope.
d = Diameter of rope in inches.
$n = 48\,d^2$ for white rope $= 35\,d^2$ for tarred rope.
r = Effective radius of pulley in inches.
T = Tension in lbs. avoirdupois.

$$R = \frac{n}{r}(\cdot 0012 + \cdot 001026\,n + \cdot 0012\,T) \text{ for white rope.}$$

$$= \frac{n}{r}(\cdot 006 + \cdot 001392\,n + \cdot 00168\,T) \text{ for tarred rope.}$$

Cranes.

Computation of Stresses by Graphic Construction.



With any convenient scale draw A B parallel to the suspending chain and equal to the load W; also draw A C parallel to the back chain and = W; complete the parallelogram by the lines C D, B D drawn parallel to A B and A C respectively. Then the line A D represents the intensity of the stress on the pin at A

From D draw a line parallel to the stay until it intersects the line of the jib at E; then D E represents the stress on the stay, and A E the stress on the jib. In this diagram no account has been taken of the stress produced by the weight of the crane itself.

A D being the resultant of the lines A B and A C will form with D E two sides of the parallelogram of forces for the crane.

CORN MILLS.

For each pair of stones with all the necessary dressing machinery, &c., it is usual to allow four horse-power nominal.

One pair of 4-feet stones will grind about five bushels of wheat per hour. Each bushel of wheat so ground per hour, requires 1·11 horse-power (indicated) exclusive of dressing and other machinery.

SPEED IN CORN MILLS.

Stones 4 ft. diameter, 140 revolutions per minute.

Dressing machines, 450 to 500 revolutions per minute, 21 inches diameter.

Creepers, 75 revolutions per minute, with $3\frac{1}{2}$ pitch.

Elevator, 40 revolutions per minute, with 18 inches diameter.

Wheat screen, 300 to 350 revolutions per minute, 18 inches diameter.

PROPORTIONS OF COCKS.

B = The bore of the cock.

Bottom diameter of plug $= B \times 1\frac{1}{4}$.

Length of plug $= B \times 3$.

Length of handle $= B \times 6$.

Taper of plug $\frac{1}{4}$ inch to each inch of length.

SPEEDS FOR GRINDING AND POLISHING, &c.

	Ft. per min.
Speed of large grindstones for polishing	2000
,, emery discs	2500 to 3000
,, polishing large articles ..	750
,, tool grinders	650
,, circular saws for hot iron ..	20,000
,, disintegrators	10,000
,, plate-bending rolls	4
,, millstones	1700
,, sack tackle	50

Speed of Cutting Tools.

Speeds for cast iron generally, 150 to 190 inches per minute, boring 80 inches per minute.

Speeds for wrought iron, about 260 to 280 inches per minute.

For yellow brass, about 300 inches per minute.

Speed of planers, about 15 feet per minute.

Speed of shapers, about 12 feet per minute.

For drilling, tapping, or boring, the speed of the circumference of the tool should be from 80 to 120 inches per minute in cast iron, and from 140 to 160 in wrought iron.

Speeds for Turning and Boring Cast Iron.

Diam. in Ins.	Revolutions per Minute.		Diam. in Ins.	Revolutions per Minute.	
	Turning.	Boring.		Turning.	Boring.
1	50·92	25·46	20	2·54	1·27
2	25·46	12·73	25	2·04	1·02
3	16·96	8·48	30	1·70	·85
4	12·74	6·37	35	1·46	·73
5	10·20	5·10	40	1·28	·64
6	8·48	4·24	45	1·12	·56
7	7·28	3·64	50	1·02	·51
8	6·36	3·18	60	·84	·42
9	5·66	2·83	70	·72	·36
10	5·10	2·55	80	·64	·32
12	4·24	2·12	90	·56	·28
15	3·40	1·70	100	·50	·25

Speed for turning chilled rolls .. 3 ft. per min.
" rifling steel guns .. .. $3\frac{3}{4}$ "
" boring cast guns .. .. 4 "
" rifling bronze guns .. 20 "
" screw cutting in steel .. $7\frac{1}{2}$ "
" drilling steel small arms 30 "
" drilling gun-metal .. 100 "

Wood-working Machinery.

Velocity of circular saws at periphery, 6000 to 7000 feet per minute. Rate of feed for circular saws, 15 to 60 feet per minute. Velocity of the band-saw, 3500 feet per minute. Velocity of gang-saws, 20-inch stroke, 120 strokes per minute. Velocity of scroll-saws, 600 to 800 strokes per minute. Velocity of planing-machine cutters at periphery, 4000 to 6000 feet per minute. Travel of work under planing machine, $\frac{1}{20}$th of an inch for each cut. Travel of moulding-machine cutters, 3500 to 4000 feet per minute. Travel of squaring-up-machine cutters, 7000 to 8000 feet per minute. Speed of wood-carving drills, 5000 revolutions per minute. Speed of machine augers, $1\frac{1}{2}$ inch diameter, 900 revolutions per minute. Speed of machine augers, $\frac{3}{4}$ inch diameter, 1200 revolutions per minute. Gang-saws require for 45 super. feet of pine per hour, 1 HP indicated. Circular-saws require for 75 super. feet of pine per hour, 1 HP indicated. In oak or hard wood, $\frac{3}{4}$ths of the above quantity require 1 HP indicated. Main shafting in wood-working shops, about 300 revolutions per minute. Mortising machines, 250 to 300 strokes per minute; stroke, 6 to 9 inches.

Sharpening Angles of Machine Cutters.

Adzing soft wood across the grain, 30°.
Ordinary soft-wood planing machines, 35°.
Gouges and ploughing machines, 40°.
Hard-wood tool cutters, 50° to 55°.

Iron-works (in Wales).

	Tons.
Yield of each puddling furnace per week	20 to 25
Ditto of balling furnace for rails ..	70 to 80
Ditto of balling furnace for small bars	35 to 45
Ditto of refining ditto	130 to 150
Ditto of blast	350 to 400
Ditto of puddling rolls	20 furnaces.
Ditto of rail train	500 to 600 tons.
Temperature of hot blast ..	600° to 1200° Fahr.
Density of blast for blast furnace	$3\frac{1}{2}$ to 8 lbs. sq. inch.
Ditto for refining furnace ..	$3\frac{1}{2}$ to 8 lbs. ,,
Number of revolutions of puddling rolls	40 to 60 per minute.
Ditto ditto rail rolls ..	100 ,,

Velocity of rail saws, 4000 to 5000 feet per minute

Power required for Different Processes.

Blast furnace, each	60 HP	indicated.
Refining ditto	26 HP	,,
Puddling rolls with squeezer and shears	80 HP	,,
Rail rolling train	250 HP	,,
Small bar train	60 HP	,,
Double rail saw	12 HP	,,
Straightening process	7 HP	,,

Speed of Rolls, &c.

Armour plate, 32 ins. diam.	150	feet	per minute.
Boiler plate 28 ,, ...	300	,,	,,
Tire rolls	300	,,	,,
Roll mills and large T & L iron rolls.	350	,,	,,
Merchant bar rolls, 15″ diam.	400	,,	,,
Small merchant bar rolls, 9″ diam. ..	450	,,	,,
Nail rod rolls	500	,,	,,
Wire rolls, 8″ diam.	750	,,	,,

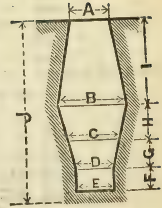
Blast Furnaces.

The accompanying table gives the interior dimensions of blast furnaces selected from different countries.

The dimensions correspond with the letters in the diagram.

In some furnaces the lines are curved so that the dimensions merely give a near approximation to their actual figure.

The dimensions are in feet.



	A.	B.	C.	D.	E.	F.	G.	H.	I.	J.
Welsh ..	10	10	17	11	8½	11	20	22	3	56
Staffordshire	6	16	16	3½	3½	4	18	6	25	53
Cleveland..	5	20	17	8	8	9	8	6	40	63
Belgian ..	9½	16½	15½	5½	5½	8½	9	14	28½	60
French ..	5	14½	5½	4	4	3	7	10	37	57
German ..	4½	13½	13½	4	4	9	6	—	36	51
American..	7½	16	16	8	6	7	11	10	19	47

STEEL MANUFACTURE. (See 'Min. Inst. Civ. Eng.,' xlii.)

Crucible or Pot Steel Process.

Puddled iron of good quality, or mild Bessemer steel scrap, is fused with manganiferous pig iron or spiegeleisen, which adds carbon and manganese.

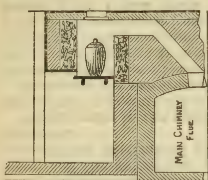
Uchatius steel is formed by melting with coke in crucible furnaces a mixture of mottled cast iron in a tolerably fine state of division, with pulverized calcined iron ore and charcoal powder. The proportions of carbon in the brands are

Brand	3	2	1	·03	·02
Percentage of carbon	·7 to ·85	·85 to ·95	·95 to 1·1	1·1 to 1·2	1·2 to 1·3
	Very soft.	Mason's tool.	Dies.	Cutting tools.	Razors.

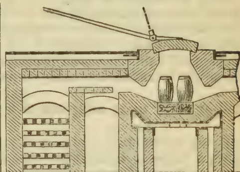
STEEL MANUFACTURE—*continued.*

The furnace is lined with gannister, a species of millstone grit; it is oval, about 2 ft. × 1 ft. 6 in., and 3 ft. 9 in. high. The passage leading from the furnace to the chimney flue is 9 in. × 9. The crucibles are generally of fire-clay, holding from 55 to 70 lbs. for the first charge, and 5 or 10 lbs. less each time they are refined. Three charges are melted in 12 hours, with a consumption of $2\frac{3}{4}$ to $3\frac{1}{4}$ of coke (equivalent to 4 or 5 tons of coal) per ton of steel melted.

POT-STEEL MELTING HOLE.



REGENERATIVE GAS POT-STEEL MELTING FURNACE.

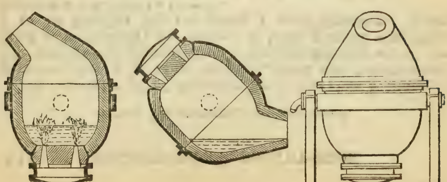


The regenerative gas furnace effects a considerable saving in fuel, requiring from 22 to 30 cwt. of small coal per ton of metal melted.

The melting chamber in the regenerative gas furnace is a long trench divided by cross walls into chambers, each holding 6 pots arranged in two rows.

In America, plumbago crucibles are used having a capacity of 1 cwt. Each pot lasts about 24 hours, yielding 5 charges with a consumption of 1 ton of small coal per ton of metal produced.

BESSEMER 5-TON CONVERTER.



STEEL MANUFACTURE—*continued.*

The converter (7′ 6″ diameter for 5 tons) has a lining of gannister from 9 to 12 inches thick, cased with boiler plates. The converter is supported on trunnions, through which the blast is introduced; the bottom is loose, pierced with from 7 to 12 fire-clay tuyeres about $\frac{3}{8}$ inch diameter. Spare bottoms are always in reserve.

Pressure of blast from 15 to 25 lbs. per square inch.

The converter is first heated to redness by a coke fire inside it, urged by a gentle blast. The fire is then turned out and the molten iron run into it whilst in a horizontal position; the blast is then put on and the converter turned into an upright position.

The air allows the carbon, silicon, and manganese to burn out, the temperature rising rapidly and the colour changing from orange to dazzling white. The silicon and manganese with a little iron burn first, and after a few minutes the carbon begins to burn freely. The length of the blow varies from 5 to 6 to 30 minutes, or even more, depending on the metal and the amount of decarbonization necessary, which is sometimes determined by the eye and sometimes by the spectrum.

In some cases in the middle of the blow from 15 to 20 per cent. of rail crop ends are added.

As soon as the spectrum bands have disappeared, the converter is turned down to a horizontal position, and a little slag taken out and cooled in water. At Seraing the colour of the slag denotes the percentage of carbon,—lemon yellow denotes 0·75 of carbon or more; orange 0·6; light brown 0·45; dark brown 0·3; bluish black 0·15. The globules of metal adhering to the slag are also tested by hammer; if a globule, of about $\frac{1}{8}$ inch diameter, flattens down too easily under the hammer with unbroken edges, the metal is too soft. If it cracks readily at the edges it is too hard. If the metal is too hard the blast is again started, and the converter brought into an upright position; if too soft, some melted manganiferous iron is added. When the metal is of the proper character it is poured out into ingots. At Seraing it is found that metal conveyed direct from the blast furnace to the converter is tougher than that obtained from a remelting cupola. Sometimes the ingots, when sufficiently cool to be removed, are hammered under a 15-ton steam hammer.

Dr. Siemens states that in America 72 "blows" have been

STEEL MANUFACTURE—*continued.*

obtained in one pit in the 24 hours, but the number and capacity of the converters in a pit is not stated.

The English practice is to blow until the carbon is reduced to about 0·1 per cent., and then to add from 3 to 5 per cent. of molten spiegeleisen, which contains 3 or 4 per cent. of carbon and 8 to 20 of manganese.

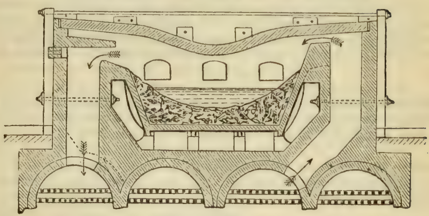
Quick "blows" and consequently great heat is favourable to sound ingots.

The loss of weight in the Bessemer process is from 9 per cent. when the iron is taken direct and 15 when it is remelted in a cupola.

The American practice is to divide the converter into four parts, keeping spare top, bottom and nose sections ready in reserve and relining the trunnion section in place. In this manner the possible make of a pair of 5-ton converters has been increased to between 45 and 50 blows in the 24 hours.

OPEN HEARTH SYSTEM.

SIEMENS' OPEN HEARTH MELTING FURNACE.



In the Siemens-Martin open hearth process, steel is produced by the dissolution of pig metal and iron ores (either raw or more or less reduced) in a bath of pig metal; the heat of the furnaces being such that the fluid bath of metal may be maintained in that condition for any reasonable length of time, during which samples may be taken and additions, either of pig metal or wrought scrap or spongy metal or ore, may be made to adjust it to the desired quality.

A sufficient quantity of pig is first melted down, then iron

STEEL MANUFACTURE—*continued.*

or steel scrap is added as fast as it dissolves, until a sample taken out in a small ladle indicates by its toughness and fracture that it is of the desired quality; then from 6 to 8 per cent. of spiegeleisen or ferro-manganese in a solid state is added, and the result is a bath of metal, the precise chemical condition of which is known; the charge is then run into ingots. This process is much used for the conversion of scrap steel and old ends into steel ingots.

The use of ferro-manganese instead of spiegeleisen allows the use of manganese with so little carbon, as to neutralize the objectionable effect of phosphorus so long as the latter does not exceed 0·25 per cent.

Mushet's tungsten steel consists of iron combined with tungsten, and cannot be forged, but if cast and ground sharp it produces cutting tools of great endurance. Chromium has also been used to produce strength and endurance in steel.

Manganese added in the proportion of 0·5 per cent. to ingot metal containing from 0·15 to 0·20 per cent. of carbon, has the effect of removing "red-shortness," and making the metal extremely malleable both when hot and cold. The furnace is heated by gas formed from small coal on Siemens' regenerative principle.

The bed is 10 feet long, 8 feet broad, and 12 or 15 inches deep in front, being more shallow behind.

The bed of the furnace is of quartzose sand sufficiently fusible to set into a hard mass at a full steel melting heat. The sand is thoroughly dried or calcined before use, and, in repairing the bottom, it is simply poured on the place to be made up, after scraping away the slag. The parts exposed to the full intensity of heat are of refractory Dinas brick, the regenerators of Stourbridge fire-brick, and the reversing flues and chimney of ordinary brick.

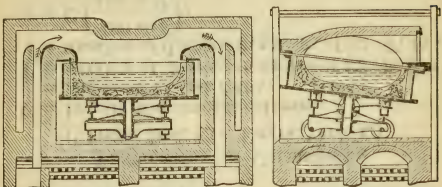
The proportion of scrap varies from 3 to 10 times the weight of pig. The time required to work a 5 or 6 ton charge is from 9 to 11 hours, 60 or 70 tons of steel being a fair week's work. The loss in converting Bessemer scrap with hematite pig is 4 or 5 per cent., and the consumption of coal 13 or 14 cwt. per ton of steel.

Iron may be produced by this process from Cleveland ore with only ·04 per cent. of sulphur and ·06 of phosphorus. The roof of the furnace will with proper care last for 150 or 200 charges.

STEEL MANUFACTURE—*continued.*

The Pernot furnace bed is mounted on wheels so as to be moved out of the furnace (which is of the ordinary regenerative gas type), it has its axis inclined at an angle of 5° or 6° from the vertical and revolves about twice per minute, is about 7½ feet internal and 9 feet external diameter and 18 inches in depth.

PERNOT'S REVOLVING OPEN HEARTH.



The pig iron previously heated to redness in an auxiliary furnace is spread uniformly over the bottom, and upon this the whole quantity of steel rail ends or scrap is charged at once. As the bed revolves the fusion is very rapid; the whole mass is liquid within 2 hours; samples are taken out at intervals, and when the metal is ready spiegeleisen or ferro-manganese is added. The average work of the furnace is 5 charges in 24 hours, and 24 per cent. pig iron, 67 per cent. scrap, 9 per cent. spiegel, yield about 4½ tons. Loss from 6 to 7 per cent., consumption of coal 8 to 8½ cwt. per ton of steel.

Ventilation in Collieries.

('Trans. Inst. Civ. Engrs.,' vol. vi.)

t = temperature of air in downcast shaft.
T = temperature of air in upcast shaft.
D = depths of the shaft in feet.
m = the periphery of the transverse section of the air-course in feet.
s = the area of the section in feet.
= the length traversed by the current in feet.
v = the velocity of the current in ft. per second.

$$v = 96\sqrt{\frac{\frac{(T - t)}{T + 448} D s}{m l + 368 s}}$$

Ventilation in Collieries.

('Trans. Inst. Civ. Engrs.,' vol. x.)

C = length of downcast column.
c = length of upcast ditto.
T = number of degrees in excess of 32° F. in C.
t = number of degrees in excess of 32° F. in c.

$$c = C\left(\frac{480 + t}{480 + T}\right).$$

Winding Engines with Flat Ropes coiled on Drum.

To find the place of meeting for ascending and descending skips.

t = thickness of rope in inches.
n = number of revolutions of the drum.
x = the distance below half the depth of the pit at which the skips will meet in yards.

$$x = \cdot 0218\, n^2 t.$$

Winding Engines—*continued.*

To find the diameter of the winding barrel for flat ropes:—

P = Depth of pit in feet.
R = Number of revolutions of engine.
T = Thickness of rope in inches.
D = Diameter of winding barrel in feet.

$$D = \frac{12\,P - 3\cdot 15\,R^2\,T}{37\cdot 7\,R}.$$

Mining Machinery.

Speed of crushing rolls at periphery	60 feet per min.
Diameter of ditto ditto ..	24 to 30 inches.
Breadth of ditto	12 to 15 "
Roller shaft	6 inches square.
Tumbling shaft	$4\frac{1}{2}$ "
Sifting screen shaft	$1\frac{3}{4}$ inch diam.
Rolls crushed together with a force of 60 tons.	
Weight of stamper heads from	$1\frac{1}{2}$ to 5 cwt.
Lift of ditto	9 to 12 inches.
Number of lifts per minute ..	45 to 60
Exposed area of cast gratings about	9″ × 6 inches.
Number of holes to the inch for tin	140
Area of stamper bottom generally	6 × 10 inches.
Pumps for deep mines, usually	8 to 10 ft. stroke.
Each lift	from 150 to 200 feet.

Horse-power of Pumping Engines.

Q = Quantity of water raised per minute, cub. ft.
H = Height in feet.
Actual horse-power = $\cdot 0023\,H\,Q$.

STEAM.

Mercurial Gauge.

* 1 atmosphere, or 14·706 lbs. per square inch	= 29·92 inches of mercury.
Each lb. pressure per square inch..	= 2·035.
Each lb. pressure per square inch..	= 1·018 rise in a siphon gauge.
	= 1 inch approximately.
Each atmosphere, or 14·706 lbs. per square inch ..	= 33·9 feet of water.
Each lb. per square inch ..	= 27·68 inches of water.

Velocity of Influx of Steam in Vacuo.

T = Temperature of steam.
V = Velocity of steam in feet per second.

$$V = 60\sqrt{T + 459}.$$

Rule for the Elastic Force of Steam.

F = The force in inches of mercury.
T = The temperature (Fahr.) of the steam.

$$F = \left(\frac{T + 100}{C}\right)^6$$

C = 177 for fresh water.
= 177·6 „ sea water
= 185·6 „ „ „ saturated with salt.

Temperature and Volume of Saturated Steam.

P = Pressure in lbs. per square inch, atmosphere included.
T = Temperature of steam in degrees Fahr.
V = Specific volume of steam or cubic feet of steam from 1 cubic foot of water.

The columns three and four in the Tables in the following pages are calculated from the following formulæ:—

$$T = \frac{2938 \cdot 16}{6 \cdot 1993544 - \log. P} - 371 \cdot 85.$$

$$V = \frac{20559}{P^{\cdot 941}}\text{; or } \log. V = 4 \cdot 3135 - (\cdot 941 \times \log. P).$$

* In common practice an atmosphere is generally taken as 15 lbs. per square inch.

Table of the Properties of Saturated Steam.

(Calculated by Lewis Olrick.)

The author is indebted to Mr. D. K. Clark for the use of his formulæ in calculating the columns three and four.

Atmosphere Included.		Temperature of Steam.	Specific Volume.	No. of Atmospheres.	Atmosphere Excluded.	
Lbs. per sq. in.	Inches of Mercury.				Inches of Mercury.	Lbs. per sq. inch.
		Fahr.				
1	2·0355	102·1	20582	·068	−27·886	−13·7
2	4·0710	126·3	10721	·136	−25·851	−12·7
3	6·1065	141·6	7322	·204	−23·815	−11·7
4	8·142	153·1	5583	·272	−21·780	−10·7
5	10·178	162·3	4527	·340	−19·744	− 9·7
6	12·213	170·2	3813	·408	−17·709	− 8·7
7	14·249	176·9	3298	·476	−15·673	− 7·7
8	16·284	182·9	2909	·544	−13·638	− 6·7
9	18·320	188·3	2604	·612	−11·602	− 5·7
10	20·355	193·3	2358	·680	− 9·567	− 4·7
11	22·391	197·8	2157	·748	− 7·531	− 3·7
12	24·426	202·0	1986	·816	− 5·496	− 2·7
13	26·462	205·9	1842	·884	− 3·460	− 1·7
14	28·497	209·6	1720	·952	− 1·425	− 0·7
14·706	29·922	212·0	1642	1·000	∓ 0·000	∓ 0·0
15	30·533	213·1	1610	1·020	0·611	0·3
16	32·568	216·3	1515	1·088	2·646	1·3
17	34·604	219·6	1431	1·156	4·682	2·3
18	36·639	222·4	1357	1·224	6·717	3·3
19	38·675	225·3	1290	1·292	8·753	4·3
20	40·710	228·0	1229	1·360	10·788	5·3
21	42·746	230·6	1174	1·428	12·824	6·3
22	44·781	233·1	1123	1·496	14·859	7·3
23	46·817	235·5	1075	1·564	16·895	8·3
24	48·852	237·8	1036	1·632	18·930	9·3
25	50·888	240·1	996	1·700	20·966	10·3
30	61·065	250·4	838	2·040	31·143	15·3
35	71·243	259·3	726	2·380	41·321	20·3
40	81·420	267·3	640	2·720	51·498	25·3

TABLE OF THE PROPERTIES OF SATURATED STEAM—*continued.*

Atmosphere Included.		Temperature of Steam.	Specific Volume.	No. of Atmospheres.	Atmosphere Excluded.	
Lbs. per sq. in.	Inches of Mercury.				Inches of Mercury.	Lbs. per sq. inch.
		Fahr.				
45	91·598	274·4	572	3·060	61·676	30·3
50	101·776	281·0	518	3·400	71·854	35·3
55	111·953	287·1	474	3·740	82·031	40·3
60	122·131	292·7	437	4·080	92·209	45·3
65	132·308	298·0	405	4·420	102·386	50·3
70	142·486	302·9	378	4·760	112·563	55·3
75	152·663	307·5	353	5·100	122·741	60·3
80	162·841	312·0	333	5·440	132·919	65·3
85	173·018	316·1	314	5·780	143·096	70·3
90	183·196	320·2	298	6·120	153·274	75·3
95	193·373	324·1	283	6·460	163·451	80·3
100	203·551	327·9	270	6·800	173·629	85·3
110	223·906	334·6	247	7·480	193·984	95·3
120	244·261	341·1	227	8·160	214·339	105·3
130	264·616	347·2	211	8·840	234·694	115·3
140	284·971	352·9	197	9·520	255·049	125·3
150	305·327	358·3	184	10·200	275·405	135·3
160	325·682	363·4	174	10·880	295·760	145·3
170	346·037	368·2	164	11·560	316·115	155·3
180	366·392	372·9	155	12·240	336·470	165·3
190	386·747	377·5	148	12·920	356·825	175·3
200	407·102	381·7	141	13·600	377·180	185·3
250	508·878	401·1	114	17·000	478·956	235·3
300	610·653	417·5	96	20·400	580·731	285·3
350	712·429	430·1	83	23·800	682·507	335·3
400	814·204	444·9	73	27·200	784·282	385·3
450	915·980	456·7	66	30·600	886·058	435·3
500	1017·755	467·5	59	34·000	987·833	485·3
600	1221·306	487·0	50	40·800	1191·384	585·3
700	1424·857	504·1	43	47·600	1394·935	685·3
800	1628·408	519·5	38	54·400	1598·486	785·3
900	1831·959	533·6	34	61·200	1802·037	885·3
1000	2035·510	546·5	31	68·000	2005·588	985·3

Joule's Mechanical Equivalent of Heat.

772 foot-pounds.

Heat requires for its production, and produces by its disappearance, 772 foot-pounds for each unit of heat. The unit being the amount necessary to increase the temperature of one pound of water by one degree Fahrenheit.

Expansion of Steam.

L = Length of stroke in inches.
l = Distance travelled by the piston before the steam is cut off.

R = Ratio of expansion $= \frac{L}{l}$.

*H = Hyperbolic Logarithm of R, see Table below.
P = Initial pressure of steam in lbs. per sq. in., including atmosphere.
p = Mean pressure during stroke in lbs. per sq. in., including atmosphere.
v = Allowance for imperfect vacuum = about $2\frac{1}{2}$ lbs. per square inch.

$$p = P\frac{1+H}{R} - v = PK - v.$$

Portion of Stroke at which Steam is cut off. l.	Ratio of Expansion. R.	Hyperbolic log. H.	K or $\frac{1+H}{R}$	Portion of Stroke at which Steam is cut off. l.	Ratio of Expansion. R.	Hyperbolic log. H.	K or $\frac{1+H}{R}$
$\frac{1}{10}$	10	2·302	·33	$\frac{6}{10}$	1·66	·507	·9[illegible]7
$\frac{1}{8}$	8	2·079	·385	$\frac{5}{8}$	1·6	·470	·9[illegible]9
$\frac{2}{10}$	5	1·609	·522	$\frac{7}{10}$	1·43	·358	·949
$\frac{1}{4}$	4	1·386	·596	$\frac{3}{4}$	1·33	·285	·966
$\frac{3}{10}$	3·33	1·203	·661	$\frac{8}{10}$	1·25	·223	·97[illegible]
$\frac{3}{8}$	2·66	·978	·744	$\frac{7}{8}$	1·14	·131	·992
$\frac{4}{10}$	2·5	·916	·766	$\frac{9}{10}$	1·11	·104	·995
$\frac{1}{2}$	2	·693	·846				

* The Hyperbolic Logarithm of any number is found by multiplying the common Logarithm of the number by 2·302585.

Expansion of Steam—*continued.*

The pressure of the atmosphere is to be included in calculating the expansion; it must therefore be deducted from the results in high-pressure engines. In condensing engines a deduction must be made for imperfect vacuum; this will amount to about $2\frac{1}{4}$ lbs. per square inch in well-proportioned engines.

Expansion of Compound Engines.

A = Area of the large cylinder.
a = " " small ditto.
L = Length of stroke.
l = Distance travelled by piston before steam is cut off in small cylinder.

$$E = \text{Rate of expansion} = \frac{A\,L}{a\,l}.$$

The mean pressure of steam in lbs. per square inch may be taken as if it acted upon the large cylinder only, and the steam were cut off at $\frac{1}{E}$th of the stroke.

The best proportion of a to $A = \frac{a}{A}\sqrt{E}$, or $a = \frac{A}{\sqrt{E}}$.

Best Proportion of Capacity of Cylinders and Point for Cutting off Steam.

No. of Times Steam is to be Expanded.	Best Point for Cutting off Steam.	Relative Capacity of Small to Large Cylinder.
4 times.	·50 L	·50 A
5 "	·45 L	·45 A
6 "	·41 L	·41 A
7 "	·38 L	·38 A
8 "	·35 L	·35 A
10 "	·32 L	·32 A
12 "	·29 L	·29 A

Table of Steam used Expansively.

Initial Pressure, lbs. per square inch.	Average Pressure of Steam in lbs. per square inch for the whole Stroke.					
	Portion of Stroke at which Steam is cut off.					
	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{1}{4}$	$\frac{1}{8}$
5	4·8	4·6	4·2	3·7	3·0	1·9
10	9·6	9·2	8·4	7·4	5·9	3·8
15	14·5	13·8	12·7	11·2	8·9	5·8
20	19·3	18·4	16·9	14·8	11·9	7·7
25	24·1	22·9	21·1	18·6	14·9	9·6
30	29·0	27·5	25·4	22·3	17·9	11·5
35	33·8	32·1	29·6	26·0	20·8	13·5
40	38·6	36·7	33·8	29·7	23·8	15·4
45	43·4	41·3	38·1	33·5	26·8	17·3
50	48·3	45·9	42·3	37·2	29·8	19·2
60	57·9	55·1	50·7	44·6	35·7	23·1
70	67·6	64·3	59·2	52·1	41·7	26·9
80	77·3	73·5	67·7	59·5	47·7	30·8
90	86·9	82·7	76·1	66·9	53·6	34·6
100	96·6	91·9	84·6	74·4	59·6	38·5
110	106·2	101·1	93·1	81·8	65·6	42·3
120	115·9	110·3	101·5	89·3	71·5	46·2
130	125·6	119·4	110·0	96·7	77·5	50·0
140	135·2	128·6	118·5	104·1	83·4	53·9
150	144·9	137·8	126·9	111·6	89·4	57·7
160	154·6	147·0	135·4	119·0	95·4	61·6
180	173·9	165·4	152·3	133·9	107·3	69·3
200	193·2	183·8	169·2	148·8	119·2	77·0

Terminal Pressure.

Rule for finding the Pressure at the end of the Stroke, or at any Point during Expansion.

P = Initial pressure of steam in lbs. per square inch, including the pressure of the atmosphere.
l = Distance travelled by the piston before steam is cut off.
L = Distance travelled by the piston when the pressure of the steam = X.
X = Pressure of steam in the cylinder, including the pressure of the atmosphere, when the piston has travelled a distance L.

$$X = \frac{P\,l}{L}.$$

Compound Engines.

A = Area of large cylinder.
a = Area of small ditto.
L = Length of stroke.
l = Distance travelled by piston before steam is cut off in small cylinder.
P = Initial pressure of steam in lbs. per square inch, including pressure of atmosphere.
p = Back pressure caused by imperfect vacuum = generally $2\frac{1}{2}$ lbs. per square inch.
w = Work performed during l portion of stroke.
W = Stroke work performed during whole stroke.
N = Number of revolutions of engine per minute.
*E = Ratio of expansion $= \dfrac{\mathrm{A\,L}}{a\,l}$.

$$w = a\,\mathrm{P}\,l\left(1 + \text{hyp. log. } \frac{a\,\mathrm{L} + (\mathrm{A} - a)\,l}{a\,\mathrm{L}}\right) - \mathrm{A}\,p\,l.$$

$$\mathrm{W} = \frac{\mathrm{A\,P\,L}}{\mathrm{E}}(1 + \text{hyp. log. E}) - \mathrm{A}\,p\,\mathrm{L}.$$

Horse-power

$$= \cdot 0000606\ \mathrm{A\,L\,N}\left[\frac{\mathrm{P}}{\mathrm{E}}(1 + \text{hyp. log. E}) - p\right].$$

Hyp. log. indicates the hyperbolic logarithm. (See Table of Hyperbolic Logarithms.)

The hyperbolic logarithm of any number is found by multiplying the common logarithm of the number by $2 \cdot 302585$.

* The limit of useful expansion is to 5 lbs. per square inch, including atmosphere.

Compound Engines—*continued.*

Best Rate for Expansion under Different Pressures.

100 lbs., excluding atmosphere,	23 times;	cut off	·21	stroke.
80 „ „ „	19 „	„	·23	„
60 „ „ „	15 „	„	·26	„
50 „ „ „	13 „	„	·28	„
40 „ „ „	9 „	„	·33	„

About 80 lbs. is the highest convenient pressure for marine engines.

Allowance for Clearance and Steam in Passages, &c.

L = Length of stroke before steam is cut off, in terms of stroke.

C = Clearance space + contents of admission port, in terms of volume displaced by the piston in its stroke. C varies from ·02 to ·10.

$$R = \text{Ratio of expansion} = \frac{1 + C}{C + L}.$$

Thus, if C = ·1, and L = ·25, then $R = \frac{1 + \cdot 1}{\cdot 1 + \cdot 25} = 3\cdot 143$ times.

Surface of Tubes in Square Feet per Foot Run.

Diameter Inches.	0	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$
0	—	·0327	·0654	·0982	·1309	·1636	·1963	·2291
1	·2618	·2945	·3272	·3600	·3927	·4254	·4581	·4909
2	·5236	·5563	·5890	·6218	·6545	·6872	·7200	·7527
3	·7854	·8181	·8508	·8836	·9163	·9490	·9817	1·0145
4	1·0472	1·0799	1·1126	1·1454	1·1781	1·2108	1·2435	1·2763
5	1·3090	1·3417	1·3744	1·4072	1·4399	1·4726	1·5053	1·5381

Friction of Air in Tubes.

(Unwin, 'Min. Inst. Civ. Eng.,' vol. lxiii.)

k = Coefficient of friction $= \frac{a}{v} + b$, a and b being constants, and v = Velocity of air, feet per second.

Diameter of tube, feet	1·64	1·07	·83	·338	·266	·164
Value of a	·00129	·00972	·01525	·03604	·0379	·0451
„ b	·00483	·0064	·00704	·00941	·00959	·01167
„ k if $v = 100$	·00484	·0065	·00719	·00977	·00997	·01212

Duty of Engines.

The duty of an engine is the number of pounds raised 1 foot high by a bushel of Welsh coal, or 94 pounds (or by 1 cwt. in recent practice).

Average duty of Cornish engines 60,000,000 = 60 millions of pounds raised 1 foot high. = $71\frac{1}{2}$ millions for 112 lb. standard.

D = Duty of an engine in millions of pounds.
C = No. of lbs. of coal consumed per indicated horse-power per hour.

$$D = \frac{186 \cdot 12}{C} \text{ for bushels; } = \frac{221 \cdot 76}{C} \text{ for cwt.}$$

Fuel.

Average Evaporative Power.

1 lb. of coke	evaporates	9 lbs.	of water.*
1 lb. of coal	„	9	„
1 lb. of slack	„	4	„
1 lb. of oak (dry)	„	$4\frac{1}{2}$	„
1 lb. of pine	„	$2\frac{1}{2}$	„

Coal loses about $\frac{1}{3}$rd of its weight in coking, but increases in bulk $\frac{1}{10}$th.

Stationary expansive condensing engines use from 4 to 7 lbs. of coal per indicated horse-power per hour. Compound engines $1\frac{3}{4}$ to 3 lbs.

Locomotives (passenger) from 20 to 30 lbs. per train mile.

„ (heavy goods) „ 40 to 55 lbs. „

Wood-burning locomotives will run 24 miles with 1 cord of wood.

A cord of wood = 4 feet × 4 feet × 8 feet.

Navy allowance of stowage of coal = 2700 lbs.; 48 cube feet per ton. The bulk of wood is about 6 times as much as an equivalent of coal.

An average of 27 kinds of coal gave about $40\frac{1}{2}$ cubic feet per ton.

* Feed-water supplied at 212° Fahr.

Relative Heating Power of Fuel. (Fritz.)

Fuel.	Theoretical.	Lbs. of Water evaporated by 1 lb. of Fuel.	
		In Steam Boilers.	In Open Boilers.
Anthracite ..	12·46	—	—
Coal	11·51	5·2 to 8	5·2
Charcoal	10·77	6 „ 6·75	3·7
Coke	9·00 to 10·8	5 „ 8	—
Brown coal ..	7·7	2·2 „ 5·5	1·5 to 2·3
Peat	5·5 „ 7·4	2·5 „ 4·5	1·7 „ 2·3
Wood	4·3 „ 5·6	2·5 „ 3·75	1·85 „ 2·1
Straw	3·0	1·86 „ 1·92	—
Gas reduced to lbs. coal..	—	4 „ 6	—

In heating boilers, on an average only 47 per cent. of the theoretical heating power of fuel is utilized, the remainder being lost through imperfect combustion, radiation, and other causes.

Relation between Effective and Theoretical Work of Fuel in Different Motors.

Small high-pressure engine without expansion	1·8
Air engine (Erricson)	1·8
„ (Leaubereau)	1·8
„ (Lehman)	1·9
Gas engine (Lenoir)	2·0
„ (Hugon)	2·0
Portable steam engine	2·8
High-pressure steam engine with expansion ..	3·0
Air engine (Leawitt)	3·5
„ (Belou)	4·1
Condensing engine with expansion	4·5
Gas engine (Otto and Langen)	5·0
Petroleum engine	8·4
Large steam engine, best make	9·0

The cost of fuel in gas engines exceeds that for steam engines from $2\frac{1}{4}$ to 5 times; so that notwithstanding the many advantages they cannot compete with steam engines,

Liquid Fuel. (H. Aydon, 'Min. Inst. C. E.,' lii.)

No alteration of the ordinary furnace or grate is necessary. For burning oil, the grate bars are covered with thin slabs, overlaid with a few cinders, and the ash-pit doors closed. In a Cornish boiler 25 ft. long and 5 ft. 6 in. diameter, with one internal flue 3 ft. diameter, the oil, American petroleum, was allowed to fall through a small orifice, about $\frac{1}{8}$ inch diameter, in a continuous stream, at the rate of about 3 gallons per hour. As the oil fell vertically, a jet of superheated steam met it and formed it into vapour, which then took fire, and was consumed in a perfect manner. The quantity of water evaporated amounted to 10 cubic feet per hour, or 20·8 lbs. of water per lb. of oil. (The average result of several days' experiment was $19\frac{1}{2}$ lbs. of water per lb. of oil. With best Aberdare coal, the same boiler evaporated only $6\frac{1}{2}$ lbs. of water per lb. of coal.) The advantages claimed for liquid fuel in sea-going vessels are—

1st. A reduction of weight of fuel amounting to 40 per cent.
2nd. A reduction of the bulk „ „ 36 per cent.
3rd. A reduction of stokers in the proportion of 4 to 1.
4th. Prompt kindling of fires.
5th. The fire can be extinguished instantaneously.
6th. Capability for stowage in the place of water ballast, by which it may be replaced as consumed, and great facility for taking in fast.
7th. Its cleanliness and freedom from ashes, cinders, &c.
8th. The avoidance of loss of heat due to the frequent opening of the furnace doors.
9th. The ability to command a more intense fire and management of temperature without forced draught.
10th. Facility for perfect combustion, and rapidity of raising steam.
11th. Freedom from smoke.

In a plate-heating furnace at Woolwich, the same plan of using petroleum was tried, showing a consumption of 780 lbs. of petroleum against 2240 lbs. of coal.

Steam Engine.

COMBUSTION.

An ordinary furnace requires 24 lbs. of air, or 300 cube feet of air for the consumption of each lb. of coal; by means of fan-blast or jet of steam this quantity of air may be decreased to 18 lbs., or 220 cube feet.

From 13 to 20 lbs. of coal may be consumed per superficial foot of fire-grate.

¾ of a foot of fire-grate are required to evaporate a cubic foot of water.

COMBUSTION OF 1 LB. OF FUEL.

	Percentage of			Units of Heat.	Air consumed, cubic feet per lb.	Relative Heat.
	Carbon.	Hydrogen.	Oxygen.			
Patent fuel	90	5·6	—	16500	163	102
Steam coal	89	5	·4	16200	161	100
Wallsend ..	83·5	6·7	8·2	15500	153	96
Average coal	80·4	5·1	7·6	14000	140	86
Coke	94·	·04	·7	13600	142	84
Peat	60	6	31	9900	100	61
Wood.. ..	50	6	41	7800	80	48

CONDENSATION.

The quantity of water required for condensation is about 20 times the amount of the feed.

SURFACE CONDENSATION.

Approximate Rule for Surface Condensers.

Area of condensing surface = heating surface × 0·7.

Tubes ¾ in. diameter outside from 7 to 10 feet long—of brass.

COMBINED STEAM.

Area of superheating surface = 1 square foot per indicated horse-power.

Combined steam should not be used at a higher temperature than 310° Fahr.

Some engineers allow 3 superficial feet per foot of water evaporated.

RELATIVE VALUE OF HEATING SURFACE.

Horizontal surfaces above the flame	= 1·00
Vertical	= ·50
Horizontal beneath the flame ..	= ·00
Tubes and flues	$1\frac{1}{4}$ of their diam.
Convex surfaces above the flame ..	$1\frac{1}{6}$ diameter

BOILERS—LAND.

RULES FOR HEATING AND GRATE SURFACES.

G = Fire-grate surface in square feet.
P = Number of nominal horse-power.
h = Heating surface in square yards.

$$P = \sqrt{h\,G}.$$

$$h = \frac{P^2}{G}. \qquad G = \frac{P^2}{h}.$$

For each nominal horse-power a boiler requires:
1 cubic foot of water per hour.
1 square yard of heating surface.
1 square foot of fire-grate surface.
1 cube yard capacity.
28 square inches flue area; 18″ over bridge.

For cylindrical double-flued boilers, an approximate rule is:—

$$\frac{\text{Length} \times \text{diameter}}{6} = \text{nominal horse-power.}$$

MOUNTINGS FOR A NOMINAL 30-HORSE BOILER.

Man-hole, oval	18 in. × 15 in.
Vacuum-valve	$2\frac{1}{2}$ in. diam. in seat
Spring-balance safety-valve ..	$2\frac{1}{2}$ in. "
Weighted safety-valve	5 in. "
Escape-valve	$2\frac{1}{2}$ in. "
Damper, area of opening	4 ft. × $13\frac{1}{2}$ in.
Damper weight	8 in. × 10 × 4.
Blow-off cock	3 in. bore.
Range of glass gauge..	10 in.
Length of dead-plate..	10 in.
Fire-doors	16 in. × 13 in.

MULTITUBULAR BOILERS.

d = Diameter of tubes in inches.
l = Length of tubes in inches.
n = Number of tubes.
H = Horse-power.
A = Sectional area of tubes in inches.

$$l = \frac{K\,H}{n\,d}; = \frac{\cdot 785\,K\,d}{A}$$

Assuming the tube surface to be about ·9 of the total heating surface.

The values of K and A vary

	K.	A.	
from	670	20	in ordinary boilers
	400	8	with very strong draught
to	250	$2\frac{1}{2}$	„ artificial blast.

RELATIVE STEAM AND WATER SPACE.

Simple boiler—total capacity = 1·63 cub. ft. per sq. ft. heating surface.

Boiler with two heaters	·98	„
Lancashire boiler	·82	„
Marine multitubular	·33 to 49	„
Portable engine	·26	„
Locomotive	·18	„

The ratio of steam space to water space is in—

Locomotives	1·00 steam to	2·00	water space.
Marine multitubular ..	1·00 „ „	1·08	„
Cornish boilers	1·00 „ „	1·33	„

The best distance for the fire below the heating surface of the flue in Cornish or Lancashire boilers is about 20 or 22 inches.

CORNISH OR LANCASHIRE BOILERS.

GENERAL MEMORANDA.

Thickness of fire-bars, $\frac{1}{2}$ to $\frac{3}{4}$ inch.
Width of fire-bar spaces, $\frac{3}{8}$ to $\frac{1}{2}$ inch.
Inclination of fire-bars, 1 in 10, to 1 in 12.
Height of dead-plate above floor of boiler-shed or stoke-hole, 2 ft. 8 in.
Minimum height of water over flue .. 4 inches.
Average „ „ „ .. 9 inches.
Inclination of cylindrical boilers towards blow-off cock in setting, $\frac{1}{2}$ inch in 10 feet.

EVAPORATIVE PERFORMANCE OF STEAM BOILERS.

(D. K. Clark, 'Min. Inst. Civ. Eng.,' vol. xlvi.)

w = lbs. of water evaporated per square foot of grate per hour.
c = lbs. of fuel consumed per square foot of grate per hour.

E = Efficiency of fuel $= \dfrac{w}{c}$.

h = Heating surface in square feet.
g = Grate surface " "

r = Ratio of heating to grate surface $= \dfrac{h}{g}$.

a = A constant varying with each boiler.
B = Coefficient of fuel consumed per square foot of grate.
A = Coefficient of water consumed $= a\,r^2$.

$$w = A + B\,c \quad = \quad a\,r^2 + B\,c.$$

$$r = \sqrt{\frac{w - B\,c}{a}} \quad = \quad \sqrt{\frac{c\,(E - B)}{a}}.$$

$$c = \frac{w - a\,r^2}{B} \quad = \quad \frac{a\,r^2}{E - B}.$$

	Minimum value of c when r =				Values of w for any Ratio, r.	Limiting Value of c.
	30	40	50	75		
Stationary	6·8	12·1	18·9	—	$·0222\,r^2 + 9·56\,c$	$·00755\,r^2$
Marine.. ..	6·3	11·2	17·5	—	$·016\,r^2 + 10·25\,c$	$·007\,r^2$
Portable.. ..	1·8	3·2	5·0	—	$·008\,r^2 + 8·6\,c$	$·002\,r^2$
Locomotive, coal ..	2·9	5·2	8·1	18·3	$·009\,r^2 + 9·7\,c$	$·00325\,r^2$
Ditto, coke ..	4·0	7·0	11·0	25	$·0178\,r^2 + 7·94\,c$	$·0044\,r^2$

For lower than the limiting values of c, the values of w are $12·5\,c$ for coal and $12\,c$ for coke.

In locomotives the limit is from 100 to 120 lbs. of coal or coke per square foot per hour.

Experiments in France gave as the average of the Lancashire, the Elephant, and the Fairbairn "5-tube" boilers, $a = ·0113$ and $B = 7·82$.

Evaporative Power of Locomotive Boilers.

(Longridge, 'Min. Inst. Civ. Eng.,' vol. lii.)

S = Surface of fire-box in square feet.
s = Surface of tubes " "
N = Number of units required to evaporate 1 cubic foot of water from 60° to temperature of water in boiler = say 71,000.
m = Units of heat transmitted per hour through 1 square foot of surface = say 11 for each degree Fahr.
x = Temperature of gases (before entering tubes from fire-box) above temperature of water = say 2100.
$h = W\,G\,\sigma\,w$.
W = lbs. of fuel consumed per square foot fire-grate per hour.
G = Surface of fire-grate in square feet.
w = Weight of gases and unconsumed air arising from the combustion of 1 lb. of fuel
σ = Specific heat of this mixture = ·237 } $w\,\sigma = 4\cdot033$.
ϵ = Base of hyp. log. = 2·718.
U = Units of heat arising from the combustion of 1 lb. fuel.

Heat generated per hour = U W G.

$$\text{Evaporation from fire-box per cube foot per hour} = \frac{S\,m\,x}{N}.$$

$$\text{Evaporation from tubes} = \frac{h\,x}{N}\left\{1 - \frac{1}{\epsilon^{\frac{m\,s}{h}}}\right\}.$$

Conclusions.—(1) No fixed rule can be established as to the best relative proportions of grate, fire-box, and tube surfaces. (2) Length of tube does not affect economic result. (3) Diameter of the tube is a matter of indifference. (4) When the quantity of fuel burnt is 50 or 60 lbs. per square foot of grate per hour, the combustion is nearly perfect; but loss results from carbonic oxide passing away unconsumed with hard firing. (5) A large increase in heating surface in proportion to coal burnt only slightly increases the economical effect.

In locomotives the economic effect is in proportion to the fourth root of the heating surface.

Cornish and Lancashire Boilers. (Havrez.)

D = Diameter of boiler in inches.
d = Diameter of flues in inches.
L = Length of shell of boiler in feet.
l = Length of fire-grate in inches.
H = Nominal horse-power at 16·9 square feet per HP.
p = Effective pressure in atmospheres.
W = Total weight of boiler in lbs.

In Cornish boilers—
Space between under side of flue and shell 4 to 6 inches.
Depth of water over flue .. .. 4 to 8 „

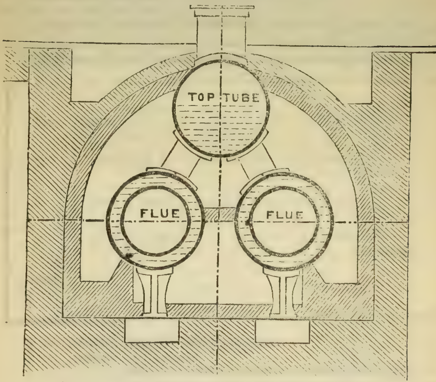
Cornish Boilers.	Lancashire Boilers.
$D = 1 \cdot 7\, d$ for Cornish boilers;	$= 2 \cdot 5\, d$ for Lancashire.
$D = 11 \cdot 42 \sqrt{H}$;	$D = 11 \cdot 4 \sqrt{H}$.
$d = 6 \cdot 72 \sqrt{H}$;	$d = 4 \cdot 56 \sqrt{H}$.
$l = 11 \cdot 8 \sqrt{H}$;	$l = 8 \cdot 65 \sqrt{H}$.
$L = 5 \cdot 1 \sqrt{H}$;	$L = 14 \cdot 4 + 0 \cdot 46\, H$.
$W = H(110 + 22\, p \sqrt{H})$;	$W = H(220 + 12 \cdot 35\, p \sqrt{H})$.

Area of chimney, 15½ square inches per horse-power.

Nominal Horse-power.	Cornish Boilers.				Lancashire Boilers.			
	Diameter of Shell.	Diameter of Flue.	Length of Boiler.	Weight of Boiler.	Diameter of Boiler.	Diameter of Flue.	Length of Boiler.	Weight of Boiler.
	inches.	inches.	feet.	tons.	inches.	inches.	feet.	tons.
10	36	21¼	16·1	2·04	—	—	—	—
20	51	30	22·8	5·37	—	—	—	—
30	62½	36¾	28	9·54	62½	25	28·2	7·48
40	72¼	42½	32·3	14·39	72	28¾	32·8	10·90
50	80¾	47½	36	19·82	80½	32¼	37·4	14·66
60	88½	52	39·5	25·77	88¼	34½	42	18·72

Pressure assumed at 5 atmospheres *effective* or 6 atmospheres *absolute*.

Fairbairn "Five-tube" Boiler.



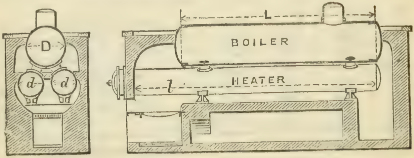
Working pressure, 150 lbs. per square inch.

LEADING DIMENSIONS AND WEIGHT.

Horse-power.	30	40	50	60
Length in feet	12	15	17	20
Diameter of shells, ins. ..	36	39	42	45
Diameter of flues, ins.	24	27	30	33
Heating surface, sq. ft. ..	449	600	974	1000
Length of grate, ft.	$4\frac{1}{2}$	5	$5\frac{1}{2}$	6
Area of grate, sq. ft.	18	$22\frac{1}{2}$	$27\frac{1}{2}$	33
Thickness of plate, ins. ..	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{7}{16}$
Weight of top tube, tons ..	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$	$2\frac{1}{4}$
Weight of bottom tubes, tons	4	$6\frac{1}{2}$	$7\frac{1}{2}$	$8\frac{1}{4}$
Weight of mountings, tons..	$1\frac{1}{4}$	2	2	$2\frac{1}{4}$
Total tons	$6\frac{1}{2}$	10	$11\frac{1}{4}$	$12\frac{3}{4}$

"French" or "Elephant" Boiler.

(See 'Trans. Inst. Civ. Eng.,' vol. xlii.)



D = Diameter of boiler in feet.
d = Diameter of heater in feet = ·6 D.
L = Mean length of the boiler and heaters.
H = Nominal horse-power at 16·9 square feet per HP.
n = Number of heaters.
S = Heating surface in square feet.

No. of heaters.		
0	$S = 16{\cdot}1\,H$;	$L = \frac{10{\cdot}75\,H}{D}$.
1	$S = 8{\cdot}05\,H + 8{\cdot}05\,H$;	$L = \frac{5{\cdot}38\,H}{D}$.
2	$S = 5{\cdot}37\,H + 10{\cdot}73\,H$;	$L = \frac{3{\cdot}58\,H}{D}$.
n	$S = \frac{16{\cdot}1\,H}{n+1} + \frac{16{\cdot}1\,H\,n}{n+1}$;	$L = \frac{10{\cdot}75\,H}{D\,(n+1)}$.

The heating surface of the heater is assumed at $\frac{5}{6}$ths of the circumference, that of the boiler $\frac{1}{2}$, and with the proportion of $d = {\cdot}6$ D, the heating surfaces of boiler and heater will be equal per unit of length.

Maximum diameter of boiler = 4 feet.
" " heater = 2 feet 3 inches.
Minimum diameter of heater = 1 foot 6 inches.

ELEPHANT BOILERS—*continued.*

WEIGHT (IN CWTS. PER HORSE-POWER) OF ELEPHANT BOILERS as usually made in France.

Horse-power.	Diameter of Boiler.	Diameter of Heater.	Effective pressure in Atmospheres.			
			3	4	5	6
	feet.	feet.	cwt.	cwt.	cwt.	cwt.
10 to 20	2·62	1·64	2·74	3·23	3·73	4·20
15 ,, 25	2·95	1·80	2·86	3·50	4·04	4·57
20 ,, 40	3·28	1·97	3·12	3·73	4·33	4·94
30 ,, 45	3·61	2·16	3·30	3·96	4·65	5·20

The disadvantages of the "Elephant" boiler are the unequal expansion of boiler and heaters, and the deposit of sediment on the portions most exposed to the fire.

BELGIAN RULE FOR THE THICKNESS OF BOILER PLATE.

D = Diameter of boiler in feet.
P = Effective pressure of steam in atmospheres.
t = Thickness of plate in inches.

For plates directly exposed to the fire, $t = \cdot0216\,DP + \cdot12$
,, beyond the fire .. .. $t = \cdot018\,DP + \cdot08$
,, not heated by the fire .. $t = \cdot0144\,DP + \cdot04$
,, the same, double riveted. $t = \cdot0115\,DP + \cdot04$
,, mild steel .. .. $t = \cdot0069\,DP + \cdot04$

EXPERIMENT ON COMPARATIVE PERFORMANCE OF BOILERS.

	Description of Boiler.		
	Lancashire.	"Elephant."	Fairbairn "Five Tube."
Water evaporated at 32° per lb. of coal	8·20	7·95	8·54
Mean temperature of gases	511°	510°	387°
Volume of air consumed cube ft. per lb. of coal	186	189	227
Diameter of boiler, feet	6·56	3·74	3·75
Diameter of flues or heaters, inches ..	27·5	20·0	27·5
Length of boiler in feet	25·75	29·5	25·75
Number of flues or heaters	2	3	2

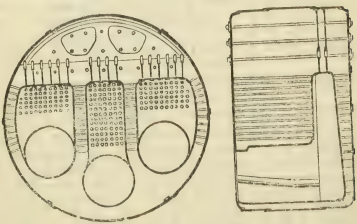
Boiler Setting.

Care should be taken to keep the boiler from contact with the brickwork, which is apt to cause rapid corrosion of the plates. Cast-iron supports should be used to keep the boiler clear from contact.

Caulking.

Caulking should not be done with too thin or too acute a tool, which for ordinary work should have its end ground to an angle 20° from a right angle, and be $1\frac{1}{4}$ inch wide $\times \frac{3}{16}$ths thick, moved about 1 inch after each blow; one blow at each place should suffice.

Marine Boiler, 400 Horse-power (Indicated).



	ft.	in.
Diameter of boiler	13	6
Length of ditto	9	0
Diameter of each furnace	4	6
Diameter of tubes (9 B.W.G.)	0	$3\frac{1}{4}$
Number of tubes	207	
Length of tubes	6	0
	sq. ft.	
Heating surface—furnace and flues	680	
" tubes	1057	
" total	1737	

Marine Boilers.

In marine engines the "nominal" horse-power varies so much from the actual or "indicated" horse-power, that the former can no longer be taken as a basis for the calculation of boiler-power.

Many screw engines work up to more than six times their nominal horse-power.

In marine compound engines the indicated horse-power consumes from $1\frac{3}{4}$ to $2\frac{1}{2}$ lbs. of coal per horse-power per hour, which requires the following proportions:—

Fire-grate area from	·13	to	·17	sq. ft.	per I.H.P.
Heating surface	„ 3·0	„	5·0	„	„
Tube area	„ ·035	„	·05	„	„
Surface condensing area, from ..	.. 2·5	„	3·0	„	„

Tubes for marine boilers are generally about $3\frac{1}{2}$ inches internal diameter, from 5 to 6 feet 6 inches long, with an inclination of about $\frac{1}{2}$ an inch to the foot.

Stays, about $1\frac{1}{8}$ diameter.

Water spaces, 5 to 6 inches wide.

Height of firing plate above stoke-hole, 2 ft. 6 in.

Length of fire-grate, 5 feet to 7 feet 6 inches.

Length of fire-bars, from 2 feet 6 inches to 3 feet

Depth of fire-bars at centre = ·12 of length.

Depth of fire-bars at ends = ·06 of length.

Clearance of fire-bars, $\frac{1}{4}$ to $\frac{3}{8}$ inch.

Taper of fire-bars, $\frac{1}{8}$ of depth.

Width of fire-bars at ends, $\frac{3}{4}$ to 1 inch.

Minimum height of water, 6 inches over flues, 8 inches over tubes.

Exhaustive Power of the Blast-pipe in Locomotives.

(Longridge, 'Min. Inst. Civ. Eng.,' vol. lii.)

d = Diameter of jet or blast-pipe in inches.
D = Diameter of chimney in inches.
p = Pressure of steam in lbs. per square inch above the atmosphere.
E = Exhaustive power in inches of water.

$$E = \frac{37\, d^{1 \cdot 662}\, p^{0 \cdot 8}}{D^2}.$$

Increased action obtained by lengthening the chimney is very slow when the length exceeds four diameters.

Area of Chimneys.

a = Area of fire-grate in square feet.
F = Quantity of coal consumed per hour in lbs.
h = Height of chimney in feet.
HP = Horse-power of engine (indicated).
A = Area of chimney at top in square inches.

$$A = \frac{15\,F}{\sqrt{h}} = \frac{100\,HP}{\sqrt{h}} = \frac{180\,a}{\sqrt{h}}.$$

General Rules for Brick Chimneys.

The diameter at the base $\frac{1}{10}$th to $\frac{1}{12}$th of the height.

Batter of chimneys, 0·3 inch to the foot.

Thickness of brickwork, 1 brick from top to 25 feet from ditto.

$1\frac{1}{2}$ brick from 25 to 50 feet from the top, increasing by $\frac{1}{2}$ brick for each 25 feet from the top.

If the inside diameter at the top exceeds 4 feet 6 inches, the top length should be $1\frac{1}{2}$ brick thick.

Velocity of Artificial Draught.

H = Height of chimney in feet.
T = Temperature of air supplying the chimney.
t = Temperature of air at top of chimney.
V = Velocity in feet per second.

$$V = 36 \cdot 5 \sqrt{H\,(T - t)}.$$

Funnels of Paddle-wheel Steamers.

For marine engines, 14 square inches area per nominal horse power is allowed.

Minimum height of water, 6 in. over flues, 8 in. over tubes.

Proportions of Locomotives, Heating and Grate Surfaces.

H = Area of heating surface in square feet.
G = Area of fire-grate in square feet.
W = Water evaporated in cube feet per hour.

$$W = \cdot 0022 \frac{H^2}{G}.$$

$$H = 21 \cdot 2 \sqrt{W G}.$$

$$G = \cdot 0022 \frac{H^2}{W} = \frac{H}{65}$$ is a common proportion.

Area of grate should not be more than $\frac{1}{90}$th heating surface, or $\frac{1}{60}$th when coal is used.

Consumption of coke about 150 lbs. per foot of fire-grate per hour.

Giffard's Injector.

Q = Quantity of water injected in gallons per hour.
P = Pressure of steam in atmospheres.
D = Diameter of throat in inches.

$$D = \cdot 0158 \sqrt{\frac{Q}{\sqrt{P}}}. \qquad Q = (63 \cdot 4\, D)^2 \sqrt{P}.$$

Diameter of Throat in decimals of an inch.	Delivery in Gallons per hour with a Pressure per square inch of				
	30 lbs.	60 lbs.	90 lbs.	120 lbs.	150 lbs.
·1	56	80	98	113	127
·15	127	180	221	255	285
·2	226	321	393	455	508
·25	354	502	615	711	793
·3	505	722	884	1021	1140

BOILERS. BOARD OF TRADE AND LLOYD'S RULES.

D = *Mean* diameter of shell in inches (D_1 = *outside* diam.).
P = Working pressure, lbs. per square inch.
F = Factor of safety (see page after next).
T = Thickness of plate in 16ths of an inch.
t = " " in inches.
p = Pitch of rivet or stay in inches.
(For diagonal riveting take $\cdot 6\,p + \cdot 4\,d$.)
d = Diameter of rivet, inches (not less than t).
n = Number of rows of rivets.
a = Sectional area of a rivet in square inches.
(For double shear take $1\cdot 75\,a$.)
R = Percentage of strength of joint or rivet (least of the two).
$= 100\dfrac{p-d}{p}$; or $100\dfrac{n\,a}{p\,t}$ for drilled, or $90\dfrac{n\,a}{p\,t}$ for punched, holes.
L = Length of flue between rings in *feet.*
S = Surface supported by stay, square inches.
G = Depth of stay girder in inches.
l = Span " "
b = Breadth " "
w = Distance apart of ditto " (centres).
K, k, Q, C, and c. Constants (see next page).

	Board of Trade.	Lloyd's.
Circular Shell	$P = \dfrac{K\,R\,t}{D\,F}$; $t = \dfrac{D\,P\,F}{K\,R}$;	$P = \dfrac{k\,t\,R}{D}$; $t = \dfrac{P\,D}{k\,R}$;
Flue or Furnace	$P = \dfrac{Q\,t^2}{D\,(L+1)}$; $t = \sqrt{\dfrac{P\,D\,(L+1)}{Q}}$;	For Superheaters multiply k by $\frac{2}{3}$.
Flat Plates	$P = \dfrac{C\,(T+1)^2}{S-6}$; $T = \sqrt{\dfrac{P\,(S-6)}{C}} - 1$;	$P = \dfrac{c\,T^2}{p^2}$; $T = \sqrt{\dfrac{P p^2}{c}}$
Collapse .		$P = \dfrac{89600\,t^2}{L\,D_1}$; $t = \dfrac{P\,L\,D_1}{89600}$
Girder Stays	$P = \dfrac{M\,G^2\,b}{l^2\,w}$ Where M = 12000 for 1 bolt, = 13500 for 2 = 12000 for 3 = 12754 for 4 bolts per girder.	

BOILERS. BOARD OF TRADE AND LLOYD'S RULES – *continued.*

VALUE OF CONSTANTS.

$K = 940$ for shells with the fibre.
$K = 800$ " against the grain.
$K = 600$ for superheaters, flame oblique.
$K = 448$ " " at right angles.

VALUES OF k.	$t =$	0 to $\frac{3}{8}$.	0 to $\frac{1}{2}$.	$\frac{3}{8}$ to $\frac{9}{16}$.	$\frac{1}{2}$ to $\frac{3}{4}$.	$\frac{9}{16}$ to $\frac{3}{4}$.	Above $\frac{3}{4}$.
Iron, lap joint punched ..	$k =$	—	155	—	165	—	170
" drilled	$k =$	—	170	—	180	—	190
" butt, 2 straps punched	$k =$	—	170	—	180	—	190
" " drilled	$k =$	—	180	—	190	—	200
Steel lap joint	$k =$	200	—	215	—	230	240
" butt, double strap ..	$k =$	215	—	230	—	250	260

VALUES OF Q. For welded seams Q = 90,000.	Holes.	Drilled.		Punched.	
	Riveting.	Double.	Single.	Double.	Single.
Butt, single strap ..	.. Q =	90,000	80,000	85,000	75,000
" double " ..	.. Q =	—	90,000	—	85,000
Lap, bevelled ..	.. Q =	80,000	70,000	75,000	65,000
" not bevelled	.. Q =	75,000	65,000	70,000	60,000

Thickness of single butt straps $= 1\frac{1}{8}\,t$; double $\frac{5}{8}\,t$ (B. of T.).
Thickness of inside butt strap $= \frac{3}{4}\,t$ (Lloyd).

VALUES OF C.	Stay fastening }	Nuts and Washers.	Nuts only.	Screwed in Plate.	
				Nut.	Riveted.
Not exposed to flame	C =	100	90	—	—
Exposed (steam contact)	C =	60	54	—	36
" (water ")	C =	—	—	80	60
VALUES OF c.	$c =$	160	140	110	90
" when t exceeds $\frac{7}{16}$	$c =$	160	140	120	100

Tensile stress not to exceed 5000 lbs. per sq. in. for iron, or 7000 for steel.

Thickness of washer $= \frac{2}{3}\,t$, Diam. = 3 diam. of stay (B. of T.).
" " $= \frac{1}{2}\,t$, " $= 0{\cdot}4$ pitch of stay (Lloyd).

BOILERS. BOARD OF TRADE AND LLOYD'S RULES—*continued.*

The factor of safety F = 5 under the following conditions: (1) Best materials; (2) Rivet-holes drilled in place; (3) All joints butt, with double straps; (4) All seams double riveted with an allowance of not more than 75 per cent. over single shear; (5) Full inspection during construction.

When these conditions are not observed, F will be increased as follows:—

	Additions to Factor of Safety for		After bending.	Before bending.	Riveting. Single.	Double.	Treble.
Longl. Seams.	Drilling out of place	—	·15	·3	—	—	—
	Punching ,,	—	·3	·5	—	—	—
	Holes not good or fair	·75	—	—	—	—	—
	Lap joints	—	—	—	1·0	·2	·1
	Butt ,, single strap	—	—	—	1·0	·3	·15
	,, ,, double ,,	—	—	—	1·0	—	—
Cross Seams.	Drilling out of place	—	·1	·15	—	—	—
	Punching ,,	—	·15	·2	—	—	—
	Holes not fair or good	·2	—	—	—	—	—
	Lap joints	—	—	—	·2	·1	—
	Butt ,, single strap	—	—	—	·2	·1	—
	,, ,, double ,,	—	—	—	·1	—	—
	Strakes not quite under and over..	·25	—	—	—	—	—
Long boilers or flues ..		·3	—	—	—	—	—
Seams improperly crossed		·4	—	—	—	—	—
Doubtful material		·4	—	—	—	—	—
Not inspected during construction		1·65	—	—	—	—	—

RULES FOR RIVETS IN SHIP-BUILDING.

d = diameter of rivet.
Minimum distance of rivet from edge of plate, &c. $= d$
Maximum pitch of rivets .. .. $= 4\ d$
Minimum ,, ,, ... $= 3\ d$
Minimum overlap single riveting .. .. $= 3\frac{1}{4}\ d$
,, ,, double ,, ... $= 5\frac{1}{2}\ d$
Pitch of rivets in outer row of treble riveting.. .. $= 8\ d$

Staying Locomotive Boilers.

FIRE-BOX WATER SPACES.

Working pressure in lbs. per square inch being $\frac{1}{6}$th of bursting pressure; stays, $\frac{3}{4}$ in. diameter; copper plates, $\frac{1}{2}$ in. thick; iron ditto, $\frac{3}{8}$ in. thick.

Stay.	Plate.		Stays 5 inches apart.	Stays 4 inches apart.
Copper	Copper	Screwed and riveted	107	185
Iron ..	Copper	Screwed and riveted	160	250
Iron ..	Copper	Screwed only	120	190
Iron ..	Iron ..	Screwed and riveted	185	290

For low-pressure boilers, at 20 lbs. per sq. in., flat portions should be stayed at intervals of 12 in. apart.

FOR TOP STAYS FOR LOCOMOTIVE FIRE-BOXES.

S = Span of stay in inches.
B = Breadth of ditto in inches.
D = Depth of ditto in inches.
L = Working load in tons.

$$L = \frac{24 . B D^2}{S}.$$

Strength of Rivets.

Shearing strength of a Lowmoor rivet in tons $= 18 d^2$ when d = diameter in inches.

Mean tensile strain of rivet-iron in tons per square inch = 26·3 Fairbairn.
25·98 Kirkaldy.

Staying Flat Surfaces in Boilers.

P = Pressure of steam in lbs. per square inch.
t = Thickness of plate in inches.
d = Distance of stays apart from centre to centre in inches.

$$d = \sqrt{\frac{16000\,t^2}{P}} = t\sqrt{\frac{16000}{P}}.$$

Pressure of Steam in lbs. per square inch.	Distance of Stays apart from centre to centre in Flat Surfaces when thickness of plate =			
	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$
	ins.	ins.	ins.	ins.
20	7·07	10·60	14·14	17·68
40	5·0	7·50	10·00	12·50
60	4·08	6·12	8·16	10·20
80	3·53	5·29	7·07	8·83
100	3·16	4·74	6·32	7·90
120	2·88	4·34	5·77	7·22
140	2·67	4·00	5·34	6·68
160	2·50	3·74	5·0	6·24
180	2·36	3·53	4·71	5·89

Collapsing Pressure in Cylindrical Boiler Flues.

P = Collapsing pressure in lbs. per square inch.
t = Thickness of plate in inches.
L = Length of tube or flue in feet.
D = Diameter of tube in inches.

$$P = 806{,}300 \frac{t^{2\cdot19}}{L\,D}\cdot \quad \text{(Fairbairn.)}$$

$$= \text{Approximately } \frac{(k\,t)^2}{L\,D} \text{ when } k = 800 \text{ in } \tfrac{1}{4}\text{-in. plate;}$$

$k = 820$ in $\frac{3}{8}$-in.; $k = 840$ in $\frac{1}{2}$ in.; $k = 860$ in $\frac{5}{8}$-in. plate.

Unwin's Formula for the Collapse of Boilers.*

For tubes with longitudinal lap joint,

$$P = 7{,}363{,}000 \frac{t^{2\cdot1}}{L^{0\cdot9}\,D^{1\cdot16}}\cdot$$

For tubes with longitudinal butt,

$$P = 9{,}614{,}000 \frac{t^{2\cdot21}}{L^{0\cdot9}\,D^{1\cdot16}}\cdot$$

For ordinary boiler flues with longitudinal and cross joints,

$$P = 15{,}547{,}000 \frac{t^{2\cdot35}}{L^{0\cdot9}\,D^{1\cdot16}}\cdot$$

Approximate formula, $P = \dfrac{t^2\,A}{L\,D\,B\,C} \times \Big\{$ Coefficient as above for character of tube.

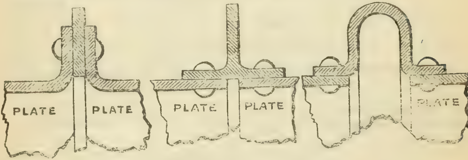
Values of A, B, and C.

When t is between	·061 &	·087 &	·119 &	·159 &	·206 &	·261 &	·325 &	·399
Then A =	·40	·45	·50	·55	·60	·65	·70	
When t is between	·399 &	·483 &	·577 &	·682 &	·80 &	·931 &	1·07	
Then A =	·75	·80	·85	·90	·95	1·0		
When L is between	13 &	25 &	51 &	110 &	253 &	628		
Then B =	·75	·7	·65	·6	·55			
When D is between	2·4 &	4·0 &	6·5 &	10·2 &	15·5 &	22·9 &	33·0 &	47
Then C =	1·2	1·3	1·4	1·5	1·6	1·7	1·8	

* In Unwin's formula, L must be in *inches*.

COLLAPSING PRESSURE IN BOILERS—*continued.*

So far as the resistance to collapse is concerned, the length of the tube or flue is practically reduced by the joints when the plates overlap each other, and the reduction is carried still further by ribs which offer increased resistance to collapse; some of the forms of these ribs are given below.



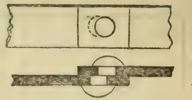
BURSTING PRESSURE OF CYLINDRICAL BOILERS.

Ultimate Tensile Strength of Plate = 43,000 lbs. per square inch.

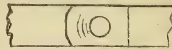
Diameter of Shell (feet).	Bursting Pressure in lbs. per square inch, with Thickness of Plate =							
	Single Riveting.				Double Riveting.			
	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$
2	501	752	1003	1254	627	940	1254	1568
$2\frac{1}{2}$	401	602	801	1005	502	752	1005	1254
3	334	501	669	836	418	627	836	1045
$3\frac{1}{2}$	286	430	573	716	358	537	716	896
4	255	376	501	627	313	470	627	783
5	202	303	401	500	251	376	500	627
6	167	250	334	418	209	313	418	522

RIVETED JOINTS. (W. R. Browne, 'Proc. I. M. E.,' 1872.)

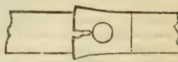
S = Breaking strain in tons.
A = Area of rivet in square inches.
d = Diameter of rivet, inches.
t = Thickness of plate, inches.


(1)

(1) RIVET SHEAR. $S = K A$.
K = 18 to 20 tons.


(2)

(2) CRIPPLING OF PLATE.
$$S = K t d.$$
K = 40 to 43 tons.
$$\frac{d}{t} = 2\cdot31 \text{ for equal strength.}$$


(3)

(3) BURSTING OF PLATE.
$$S = \frac{K t L^2}{d}.$$
K = 38 tons, $L = d$, when $d = 2t$. $L = \cdot85\,d$ when $d = 1\frac{1}{2}\,t$.


(4)

(4) TEARING OF PLATE.
$$S = K t (b - d).$$
K = 18 for punched and 22 tons for drilled plates.

Joint.	Riveting.	Holes.	Covers.	Diam. of Rivet.	Lap, or Cover.		Pitch of Rivets.	Strength of Joint to Plate.
Lap	Single	Punched	—	$2\,t$	$3\,d$		$3\,d$	·55
,,	,,	Drilled	—	$2\,t$	$3\,d$		$3\cdot6\,d$	·62
Butt	,,	Punched	1	$2\,t$	$6\,d$		$3\,d$	·55
,,	,,	Drilled	1	$2\,t$	$6\,d$		$3\cdot6\,d$	·62
Butt	,,	Punched	2	$1\frac{1}{4}\,t$	$6\,d$		$3\cdot25\,d$	·57
,,	,,	Drilled	2	$1\frac{1}{4}\,t$	$6\,d$		$3\,d$	·67
					Chain.	Zigzag.		
Lap	Double	Punched	—	$2\,t$	$5\frac{1}{2}\,d$	$6\,d$	$4\frac{1}{2}\,d$	·69
,,	,,	Drilled	—	$2\,t$	$5\,d$	$5\frac{1}{2}\,d$	$4\,d$	·75
Butt	,,	Punched	1	$2\,t$	$11\,d$	$12\,d$	$4\frac{1}{2}\,d$	·69
,,	,,	Drilled	1	$2\,t$	$10\,d$	$11\,d$	$4\,d$	·75
Butt	,,	Punched	2	$1\frac{1}{4}\,t$	$11\,d$	$13\,d$	$5\frac{1}{2}\,d$	·72
,,	,,	Drilled	2	$1\frac{1}{4}\,t$	$10\,d$	$12\,d$	$4\frac{3}{4}\,d$	·79

Riveting for Boilers.

Table of Dimensions of Rivets, &c., for Steam Boilers.

Thickness of Plate.	Diameter of Rivet.	Length of Rivet from Head.	Distance apart of Rivets, centre to centre.	Breadth of Lap. Single Riveting.
inches.	inches.	inches.	inches.	inches.
$\frac{3}{16}$	$\frac{3}{8}$	$\frac{7}{8}$	$1\frac{1}{4}$	$1\frac{1}{4}$
$\frac{1}{4}$	$\frac{1}{2}$	$1\frac{1}{8}$	$1\frac{1}{2}$	$1\frac{1}{2}$
$\frac{5}{16}$	$\frac{5}{8}$	$1\frac{3}{8}$	$1\frac{5}{8}$	$1\frac{7}{8}$
$\frac{3}{8}$	$\frac{3}{4}$	$1\frac{5}{8}$	$1\frac{3}{4}$	2
$\frac{1}{2}$	$\frac{13}{16}$	$2\frac{1}{4}$	2	$2\frac{1}{4}$
$\frac{5}{8}$	$\frac{15}{16}$	$2\frac{3}{4}$	$2\frac{1}{2}$	$2\frac{3}{4}$
$\frac{3}{4}$	$1\frac{1}{8}$	$3\frac{1}{4}$	3	$3\frac{1}{4}$

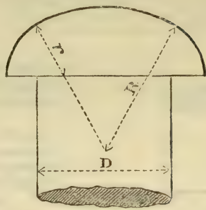
For double-riveted joints add $\frac{2}{3}$rds of the breadth of lap.

Rivets used in Ship-building.

Thickness of Plate.	Diameter of Rivet. Liver-pool.	Dock-yard.	Lloyd's.	Millwall. Diameter of Rivet.	Length counter-sunk.	Length Snap point.
inches.	inches.	inches.	inches.	inches.	inches.	inches.
$\frac{5}{16}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{5}{8}$	$1\frac{1}{8}$	$1\frac{1}{2}$
$\frac{3}{8}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{5}{8}$	$1\frac{1}{4}$	$1\frac{5}{8}$
$\frac{7}{16}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{5}{8}$	$1\frac{3}{8}$	$1\frac{3}{4}$
$\frac{1}{2}$	$\frac{13}{16}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$1\frac{1}{2}$	2
$\frac{9}{16}$	$\frac{13}{16}$	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{3}{4}$	$1\frac{11}{16}$	$2\frac{3}{16}$
$\frac{5}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	$1\frac{15}{16}$	$2\frac{3}{8}$
$\frac{11}{16}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$2\frac{3}{16}$	$2\frac{5}{8}$
$\frac{3}{4}$	$\frac{15}{16}$	1	$\frac{7}{8}$	$\frac{7}{8}$	$2\frac{3}{8}$	$2\frac{3}{4}$
$\frac{13}{16}$	1	1	$\frac{7}{8}$	$\frac{7}{8}$	$2\frac{1}{2}$	$2\frac{7}{8}$
$\frac{7}{8}$	$1\frac{1}{8}$	$1\frac{1}{8}$	1	1	$2\frac{5}{8}$	3
$\frac{15}{16}$	$1\frac{3}{16}$	$1\frac{1}{8}$	1	1	$2\frac{3}{4}$	$3\frac{1}{8}$
1	$1\frac{1}{4}$	$1\frac{1}{8}$	1	1	$2\frac{7}{8}$	$3\frac{1}{4}$

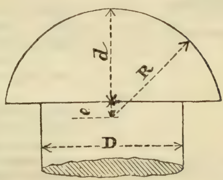
Proportions of Rivet-heads.

ELLIPSOIDAL.



D = Diameter of rivet.
R = Large radius = D.
r = Small radius = $\cdot 4\,D$.
d = Depth of head at centre = $\frac{1}{2}\,D$

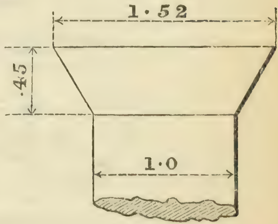
SEGMENTAL.



D = Diameter of rivet.
d = Depth of head at centre = $\frac{5}{8}\,D$.
R = Radius of rivet-head = $\frac{3}{4}\,D$.
e = Depth of centre below shoulder = $\frac{1}{8}\,D$.

Proportions of Rivet-heads—*continued.*

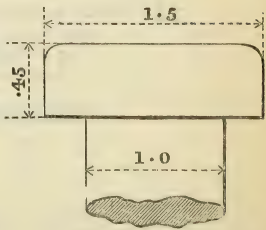
Countersunk rivets.



The countersink should be at an angle of 60°, and in any case the countersinking should not extend beyond ¾ths of the thickness of the plate.

Diameter of rivet, D=1·0.
Depth of countersink .. .. = ·45 D.
Extreme diameter of head .. = 1·52 D.

Cheese-headed rivets.

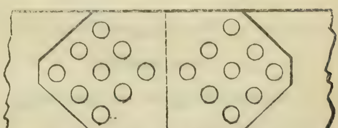


Depth of head = ·45 D.
Diameter of head = 1·5 D.

Riveted joints in tension.

In joints of the character shown in the diagram the plate is only weakened to the extent of one rivet-hole.

The rivets near the point are sometimes of smaller diameter than the rest.



Horse-power (Indicated).

A = Area of piston in square inches.
D = Diameter of piston in inches.
P = Average pressure of steam in lbs. per square inch in cylinder.
S = Length of stroke in feet.
R = Number of revolutions per minute.
r = Number of revolutions per second.
I = Indicated horse-power.

$$I = \frac{2\,A\,P\,R\,S}{33000} = \cdot 0000476\,D^2\,P\,R\,S.$$

$$I = \frac{2\,A\,P\,r\,S}{550} = \cdot 002856\,D^2\,P\,r\,S.$$

Nominal Horse-power.

"Nominal" horse-power means very little; the term is arbitrary and varying. The actual or indicated horse-power varying in stationary engines from $2\frac{1}{2}$ to 3 times the nominal horse-power, and in marine engines it is sometimes 6 or 7 times the nominal horse-power. It is now becoming obsolete for marine engines.

ORDINARY RULES FOR NOMINAL HORSE-POWER.

V = Mean velocity of piston in feet per minute.
D = Diameter of cylinder in inches.
S = Stroke of engine in feet.
H = Nominal horse-power of engine.

$$H = \frac{D^2\sqrt[3]{S}}{15 \cdot 6} \text{ for high pressure.}$$

$$D = \sqrt{\frac{15 \cdot 6\,H}{\sqrt[3]{S}}}. \qquad V = 128\sqrt[3]{S}.$$

$$H = \frac{D^2\sqrt[3]{S}}{47} \text{ for condensing engines.}$$

$$D = \sqrt{\frac{47\,H}{\sqrt[3]{S}}}. \qquad V = 128\sqrt[3]{S}.$$

French Horse-power (Force de Cheval).

1 French horse-power = 75 kilogrammètres (542·486 foot-lbs.) per second.

1 force de cheval = ·986337 horse-power.

1 horse-power = 1·01385 force de cheval.

D = Diameter of cylinder in mètres.
S = Length of stroke in mètres.
R = Number of revolutions per minute.
P = Average pressure on piston in kilogs. per square centimètre.

Indicated French horse-power = $3 \cdot 49\, D^2 P R S$.

General Rules for Engines.

Friction of Engines Unloaded.

P = Pressure of steam in lbs. per square inch necessary to overcome the friction of an engine.
D = Diameter of cylinder in inches.

$$P = \frac{18}{\sqrt{D}}.$$

Lap and Lead of the Slide-valve.

W = Width of 1 steam-port in inches.
L = Lap in inches.
l = Lead in ditto.
S = Stroke of engine.
T = Travel of the slide.
X = The distance travelled by the piston before the steam is cut off.

$$X = S\left[1 \cdot 0 - \left(\frac{2L + l}{T}\right)^2\right].$$

$$L = \left(\tfrac{1}{2} T \sqrt{\frac{S - X}{S}}\right) - \tfrac{1}{2} l.$$

$$T = 2L + 2W.$$

SLIDE-VALVE—*continued.*

S = Stroke of piston.
x = Distance travelled by the piston before the steam is cut off.
y = Distance of piston from end of stroke before exhaust is cut off.
z = Ditto, ditto, before exhaust begins.
L = Steam lap.
l = Lead of valve.
f = Eduction overlap.
T = Travel of slide.
t = Linear advance = $L + l$.
a = Angle of advance.
b = Angle of eccentric.
c = Angle of crank = $a + 90° - b$.
d = Angle of eduction overlap.

$$\text{Sin. } a = \frac{2\,t}{T}\,;\ \text{cosin. } b = \frac{2\,L}{T}\,;\ \text{cosin. } d = \frac{2\,f}{T}\,.$$

$$x = \frac{S}{2}(1 + \text{cosin. } c).$$

$$y = \frac{S}{2}[1 - \text{cosin. } (a + 90° - d)].$$

$$z = \frac{S}{2}[1 - \text{cosin. } (a + d - 90°)].$$

TABLE OF LENGTH OF LAP REQUIRED TO CUT OFF STEAM AT DIFFERENT PARTS OF THE STROKE.

Travel of Slide.	Portion of Stroke in Full Steam.								
	$\frac{1}{4}$	$\frac{1}{3}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{2}{3}$	$\frac{3}{4}$	$\frac{5}{6}$	$\frac{7}{8}$
ins.									
4	1·73	1·63	1·58	1·41	1·22	1·15	1·00	·82	·71
6	2·60	2·45	2·37	2·12	1·84	1·73	1·50	1·22	1·06
8	3·46	3·26	3·16	2·83	2·45	2·31	2·00	1·63	1·41
10	4·33	4·08	3·95	3·53	3·06	2·89	2·50	2·04	1·77
12	5·20	4·90	4·74	4·24	3·67	3·46	3·00	2·45	2·12
14	6·06	5·71	5·53	4·95	4·28	4·04	3·50	2·86	2·47
16	6·93	6·53	6·32	5·65	4·90	4·62	4·00	3·26	2·83
18	7·80	7·35	7·11	6·36	5·51	5·19	4·50	3·67	3·18
20	8·66	8·16	7·90	7·07	6·12	5·77	5·00	4·08	3·54
22	9·53	8·98	8·69	7·78	6·73	6·35	5·50	4·49	3·89
24	10·39	9·80	9·48	8·48	7·35	6·93	6·00	4·90	4·24

Note.—If lead is given, one-half of the lead must be deducted from the tabular numbers.

HIGH-PRESSURE ENGINES, WITH VERTICAL BOILERS.

	Nominal Horse-power.					
	2	4	6	8	10	12
Diameter of boiler ..	2′ 6″	3′ 3″	3′ 9″	4′ 6″	4′ 9″	5′
Height of ditto ..	5′	6′ 9″	8′	8′ 6″	10′	11′
Diameter of cylinder	5″	7″	9″	10″	11″	12″
Length of stroke ..	8″	10″	11″	12″	13″	14″
Revolutions per min.	200	150	135	125	115	110
Weight packed (tons)	$1\frac{1}{4}$	$2\frac{1}{2}$	$2\frac{3}{4}$	5	$6\frac{1}{2}$	$7\frac{3}{4}$

PORTABLE ENGINES (Single Cylinder).

	Nominal Horse-power.				
	4	6	8	10	12
Diameter of cylinder, ins.	$6\frac{1}{2}$	8	9	10	12
Length of stroke, ins. ..	10	12	13	14	15
Revolutions per minute ..	150	125	115	110	100
Weight in tons, packed ..	3	$4\frac{3}{4}$	$5\frac{1}{4}$	6	$6\frac{1}{2}$

PORTABLE ENGINES (Double Cylinder).

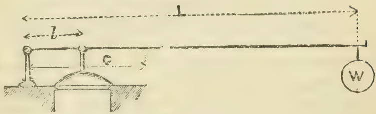
	Nominal Horse-power.				
	10	15	20	25	30
Diameter of cylinder, ins.	$7\frac{1}{2}$	9	10	12	13
Stroke in inches	12	13	14	16	18
Revolutions per minute ..	125	115	110	95	85
Weight, packed, in tons ..	6	$7\frac{1}{2}$	$11\frac{3}{4}$	$12\frac{1}{4}$	15

The weights given in these Tables are only approximate.

Proportions of Safety-valve, Levers, &c.

D = Diameter of valve in inches.
A = Area of valve in inches.
W = Weight in lbs.
P = Pressure in lbs. per square inch on the safety-valves.

$$P = \frac{W\,L}{A\,l}.$$



The proportion of $l = D$ and $L = D\,A$ gives 1 lb. per square inch for each lb. at the end of the lever.

In addition to the weight W, the weight of the lever and the valve itself must be allowed for.

Let G = Distance of centre of gravity of lever from fulcrum.
w = Weight of lever.
X = Weight of the valve.

$\frac{G\,w}{l\,A} = \Big\{$ Pressure per square inch due to the weight of lever.

$\frac{X}{A} = \Big\{$ Pressure per square inch, due to the weight of the valve.

The mitre of safety-valves should not exceed $\frac{1}{16}$ inch in width.

Area of Safety-valves.

A = Area of fire-grate.
a = Area of safety-valve.
$a = \cdot 006$ A.

For land engines the proportion of ·8 inch per nominal horse-power is sometimes adopted.

SAFETY-VALVES. (FRENCH PRACTICE.)

Two Safety-valves to each Boiler.

S = Heating surface of boiler in square mètres.
P = Pressure of steam in atmospheres.
D = Diameter of each valve in centimètres.

$$*D = 2 \cdot 6 \sqrt{\frac{S}{P - \cdot 412}}.$$

TABLE OF DIAMETERS OF SAFETY-VALVES IN MILLIMÈTRES FOR DIFFERENT PRESSURES.

Heating Surface in square mètres.	Pressure of Steam in Atmospheres.						
	2	3	4	5	6	7	8
	mill.	mill.	mill.	mill.	mill.	mill.	mill.
5	46	36	31	27	24	22	21
10	65	51	43	38	35	32	30
15	80	62	53	47	42	38	36
20	92	72	61	54	49	45	42
25	103	81	69	60	55	50	47
30	113	88	75	66	60	55	52
40	130	101	86	75	69	64	59
50	145	113	96	84	76	70	67
60	158	121	106	94	84	78	73

* EQUIVALENT FORMULA IN ENGLISH MEASURE.

Two Safety-valves.

S = Heating surface in square yards.
P = Pressure in atmospheres.
D = Diameter of each safety-valve in inches.

$$D = \cdot 945 \sqrt{\frac{S}{P - 1 + 558}}.$$

COLD-WATER AND FEED PUMPS.

Q = Cube feet of water required per horse-power per minute.
S = Stroke of pump in inches.
N = Number of strokes per minute.
H = Horse-power of the engine.

$$D = \text{Diameter of pump} = \sqrt{\frac{H\,Q\,2200}{S\,N}}.$$

The cold-water pump usually = diameter of cylinder × 0·3 when stroke = $\frac{1}{2}$ stroke of engine.

The cold-water pump usually = diameter of cylinder × 0·42 when stroke = $\frac{1}{4}$ stroke of engine.

Velocity of water in pump-passages should not exceed 500 feet per minute. Pump-valves should not be of less area than $\frac{1}{4}$ area of the pump.

Feed-pumps for High-pressure Engines:

Diameter = $\frac{1}{11}$ diameter of cylinder when pump's stroke = stroke of the engine.

Diameter = $\frac{1}{8}$ diameter of cylinder when $\frac{1}{2}$ stroke of the engine.

Diameter = $\frac{1}{6}$ diameter of cylinder when $\frac{1}{4}$th stroke of the engine.

Feed-pumps for Condensing Engines:

Diameter = $\frac{1}{11}$ diameter of cylinder when $\frac{1}{2}$ stroke of the engine.

Diameter = $\frac{1}{8}$ diameter of cylinder when $\frac{1}{4}$th stroke of the engine.

INJECTION WATER.

Q = Quantity of water required per nominal horse-power in cube feet per minute.
T = Temperature of the steam in degrees Fahr.
Q = T × 00304.

For temperature of steam, see Table.

Approximately 0·8 cube foot, or 5 gallons are required per nominal horse-power per minute.

FEED-WATER.

C = Cubic contents of cylinder and of one steam passage.

c = Cubic contents of displacement of pump-plunger.

S = Specific volume of steam (varying with the pressure), see Table, "Specific Volume."

$$c = \frac{4\,C}{S}.$$

Approximately about ·07 cube foot, or nearly ½ gallon per nominal horse-power per minute for condensing stationary engines.

FEED-WATER IN EXPANSIVE ENGINES.

A = Area of piston in inches.

S = Stroke of engine in feet.

R = Number of revolutions per minute.

x = Ratio of admission of steam; stroke being = 1.

v = Specific volume of steam corresponding to the pressure of steam on admission to the cylinder.

Q = Cubic feet of steam consumed per hour, allowing for loss in passages, piston clearance, leakage, &c.

q = Cubic feet of water to be evaporated per hour.

$$Q = 1{\cdot}05\,A\,S\,R\,x; \qquad q = \frac{Q}{v}.$$

Fire-grate area in Cornish or Lancashire boilers about = $\cdot 72\,q$.

Steam-engine Governor.

L = Vertical height from plane of revolution to point of suspension in inches.
R = Number of revolutions per minute.

$$R = \frac{187 \cdot 5}{\sqrt{L}}. \qquad L = \left(\frac{187 \cdot 5}{R}\right)^2.$$

Weight of Rim of Fly-wheel.

D = Mean diameter of rim in feet.
P = Total average pressure on piston in lbs.
S = Stroke in feet.

$$W = \text{Weight of rim in cwts.} = \frac{P\,S}{45\,D}.$$

$$\text{Sectional area of rim in inches } \frac{11 \cdot 42\,W}{D}.$$

D = Stroke $\times\ 3\frac{1}{2}$ or 4 generally.

For engines with high expansion or with irregular loads multiply W as found above by $1 \cdot 5$. Some engineers make $W = 100$ lbs. for each indicated horse-power.

In corn mills the velocity of the periphery of the fly-wheel must exceed the velocity of the periphery of the stones, to prevent back lash.

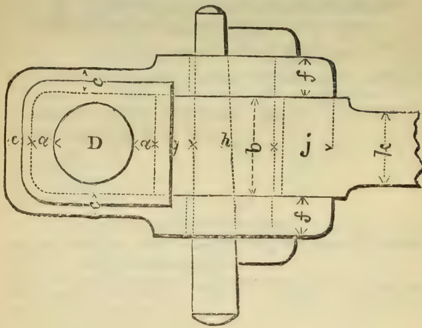
Weight of Fly-wheel Rim. (Another Rule.)

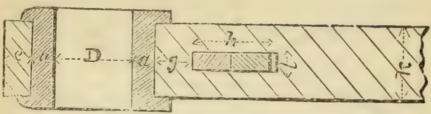
P = Pressure on piston in tons.
S = Stroke of engine in feet.
D = Mean diameter of rim in feet.
N = Number of revolutions per minute.
C = Constant varying from 3 to 4 in ordinary engines, and rising to 6 when great uniformity is required.
W = Weight of fly-wheel rim in tons.

$$W = \frac{\cdot 6366\,P\,S\,C}{D}\left(\frac{N}{60}\right).$$

Maximum safe velocity for cast iron = 80 feet

Connecting-rod Ends.



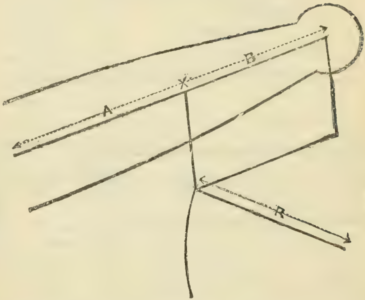


D = Diameter of bearing in inches.

$a = \cdot 1\,D + \cdot 15.$	$g = \cdot 35\,D + \cdot 12.$
$b = D + 1\cdot 4\,a.$	$h = D.$
$c = \cdot 3\,D + \cdot 06.$	$j = \cdot 5\,D + \cdot 4.$
$e = \cdot 33\,D + \cdot 06.$	$k = \cdot 9\,D.$
$f = \cdot 37\,D + \cdot 12.$	$l = \cdot 2\,D + \cdot 06.$

Taper of key 1 in 16.

Parallel Motion.



A = Length from centre of beam to centre of air-pump stud.

B = Length from centre of air-pump studs to centre of cylinder-studs.

R = Length of radius-rods.

$$R = \frac{A^2}{B}.$$

$R = A$ when $A = B$.

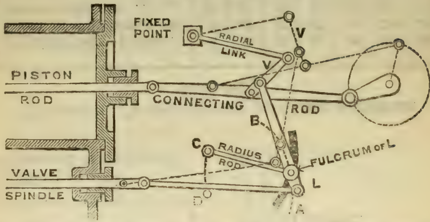
Length of back and front links $= \frac{1}{2}$ stroke.

To find the Versed Sine of the Arc described by the Beam of an Engine.

S = Stroke of the engine in inches.
R = Radius of arc described, in inches.
V = Versed sine in inches.

$$V = R - \sqrt{R^2 - (\tfrac{1}{2} S)^2}.$$

Joy's Valve Motion.



The essential features of the motion are a vibrating link V to which motion is given by a point in the connecting rod; and a lever L, one end of which is moved by a point in V, and the other end is connected with the slide-valve, whilst its fulcrum is forced by a radius-rod to travel through a curved path. The reversing is effected by moving the end of the radius-rod from C to D so as to alter the curved path of the fulcrum to the dotted line A B.

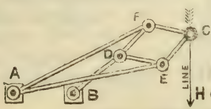
A movable slotted link may be substituted for the radius-rod.

The dotted lines show another position of the motion.

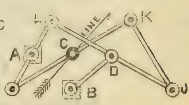
Peaucellier Parallel Motion.

The distance apart of the fixed points A and B must always = the length of the spare link BD; C is the point that moves in a straight line; DE = FC = DF = EC; AF = AE; HL = JK; KH = LJ; HA = ½ HL; JD = ½ JL; HC = ½ HK.

PEAUCELLIER'S.



HART'S MODIFICATION.



Though Hart's modification has fewer links it has more joints than Peaucellier's.

High-pressure Engines.

Diameter of cylinder in inches	= D.
Stroke	= 2 D to $2\frac{1}{2}$ D.
Depth of piston ..	= ·25 D.
Diameter of piston-rod	= ·15 D.
Thickness of metal of cylinder in inches	= ·06 D + ·2.
Thickness of ribs of cylinder	= ·3 thickness of metal.
Length of ports = L	= ·7 D.
Area of port	= ·057 area of cylinder.
Width of exhaust ..	= 1·5 width of steam-port.
Diameter of slide-valve spindle ..	= ·09 D.
Length of connecting rod	= stroke × 2.
Diameter of connecting rod at end ..	= ·19 D.
Swell of ditto	= $\frac{1}{16}$th inch per foot of length of rod.
Diameter of crank-pin	= ·23 D.
Length of ditto ..	= ·34 D.
Diam. of crank-shaft	= ·33 D.

Nominal Horse-power of High-pressure Engines.

Nominal horse-power ..	5	10	15	20	30	40	50
Diam. of cylinder in ins.	8	11	13	15	18	20	22
Stroke in inches	18	24	29	33	40	45	50

Approximate Rules for the Proportions of Stationary Condensing Engines.

D = Diameter of cylinder in inches.
S = Stroke of engine in inches.
S = from 2 D to $2\frac{1}{2}$ D.
Area of ports = area of cylinder × ·06.
Diameter of air-pump = D × 0·6.
Stroke of air-pump = $\frac{1}{2}$ S.
Area of foot-valve = area of air-pump × ·25.
Area of delivery-valve = area of foot-valve.
Capacity of condenser = capacity of cylinder × ·6.
Diameter of piston-rod = D × 0·1.
Diam. of air-pump rod = diam. of air-pump × 0·1.
Diameter of crank-pin = D × ·14.
Length of crank-pin = D × ·21.
Diameter of crank-shaft journal = D × ·3.
Length of crank-shaft journal = D × ·44.
Length of connecting rod = S × 3.
Area of connecting rod at centre = area of cylinder × ·056.
Area of connecting-rod straps = area of piston-rod.
Distance of keyway from edge of butt = $\frac{1}{2}$ diameter of crank-pin.
Depth of gib and cutter = $\frac{2}{3}$ diameter of crank-pin.
Depth of gib at centre = depth of cutter at centre.
Taper of key = $\frac{1}{2}$ inch per foot.
Length of key = breadth of butt and strap × 2.
Width of key = $\frac{1}{4}$ the width of butt.
Depth of large eye of crank = diameter of shaft.
Thickness of metal round eye = $\frac{1}{3}$ diam. of shaft.
Depth of small eye of crank = $\frac{3}{4}$ diam. of shaft.
Diameter of motion-rods = D × ·04.
Swell of ditto = $\frac{1}{4}$ inch per lineal foot.
Diameter of valve-spindle = piston-rod × 0·4.
Area of steam-pipe = area of steam-port × 1·1.

Approximate Rules for Stationary Engines—*continued.*

Rule for the Sectional Area of the Beam at Centre.

P = Total pressure on piston in lbs.
L = Length from axis of cylinder to centre of beam (or $\frac{1}{2}$ the length of beam) in inches.
D = Depth of beam in inches.
A = Sectional area of beam at centre in square inches.

$$A = \frac{P\,L}{500\,D}.$$

Depth of beam at centre = diameter of cylinder.
" " ends = depth at centre × 0·4.
Length of beam from centre to centre = stroke of engine × 3.
Width of flanges at centre = $\frac{1}{4}$ depth at centre.
" " ends = $\frac{1}{2}$ width at centre.

Dimensions of Stationary Condensing Engines. (From actual Practice.)

Horse-power, Nominal.	Diameter of Cylinder.	Length of Stroke.	Number of Strokes.	Diameter of Air-pump.	Length of Beam.	Length of Connecting Rod.	Area of Steam-port.	Diameter of Piston-rod.	Diameter of Air-pump Rod.	Diameter of Steam-pipe.
	ins.	feet.		ins.	feet.	feet.	ins.	ins.	ins.	ins.
20	24	5 0	21	14·7	15·0	15·0	11 × $2\frac{1}{2}$	$2\frac{1}{2}$	$1\frac{9}{16}$	$6\frac{1}{4}$
30	29	6 0	21	17·8	18·0	18·0	13 × 3	$2\frac{7}{8}$	$1\frac{7}{8}$	$7\frac{1}{2}$
40	$32\frac{1}{2}$	6 0	21	20	18·0	18·0	14 × $3\frac{1}{2}$	$3\frac{5}{16}$	$2\frac{3}{16}$	8
50	36	6 0	19	22·2	18·0	18·0	16 × 4	$3\frac{1}{2}$	$2\frac{1}{4}$	9
60	$39\frac{1}{2}$	7 0	$17\frac{1}{2}$	24·5	21·0	21·0	17 × $4\frac{1}{4}$	$3\frac{7}{8}$	$2\frac{1}{2}$	$9\frac{3}{4}$
70	43	7 0	$17\frac{1}{2}$	26·3	21·0	21·0	$17\frac{1}{4}$ × 5	$4\frac{1}{4}$	$2\frac{5}{8}$	$10\frac{3}{4}$
80	$46\frac{1}{4}$	7 0	$17\frac{1}{2}$	28·3	21·0	21·0	19 × $5\frac{1}{4}$	$4\frac{5}{8}$	$2\frac{3}{4}$	$11\frac{1}{2}$
90	$48\frac{1}{4}$	8 0	15	29·7	24·0	24·0	19 × $5\frac{3}{4}$	$4\frac{3}{4}$	$2\frac{7}{8}$	12
100	$51\frac{1}{2}$	8 0	15	34·2	24·0	24·0	20 × 6	$5\frac{1}{2}$	$3\frac{1}{8}$	$12\frac{3}{4}$

Approximate Rules for the Proportions of Locomotives.

Area of steam-ports	$= D^2 \times \cdot08$.
Area of eduction-port	$= D^2 \times \cdot18$.
Diameter of piston-rod	$= \frac{D}{7}$. $D \times \cdot16$.
Diameter of feed-pump plunger	$= D \times \cdot12$ if of the same stroke as the engine.
Diameter of feed-pipe	$= D \times \cdot12$.
Diameter of valve-spindle ..	$= D \times \cdot09$.
Diameter of outside crank-pin ..	$= D \times \cdot26$.
Length of " " ..	$= D \times \cdot28$.
Diameter of boiler	$= D \times 3\cdot11$.
Diameter of steam-pipe	$= D^2 \times \cdot02$.
Diameter of blast-pipe	$= D \times \cdot3$.
Diameter of piston-rod	$= D \times \cdot16$.
Thickness of piston	$= D \times \cdot28$.
Diam. of connecting-rod ends ..	$= D \times \cdot16$.
" " middle	$= D \times \cdot21$.
Diameter of crank-axle	$= D \times \cdot4$.
Length of journal of crank-axle	$= D \times \cdot43$.
Capacity of tenders in gallons ..	$= D \times 90$.
Capacity of tanks of tank-engines, in gallons	$= D \times 60$.
Heating surface	$= 65$ area of fire-grate.

Rule for the Lap and Lead of Locomotive Slide.

$T =$ Travel of slide in inches.
$L =$ Lap of slide in inches.
$l =$ Lead of slide in inches.
$L = T \times 0\cdot22$.
$l = T \times 0\cdot07$.

Rule for the Strength of Locomotive Springs.
(D. K. Clark.)

$S =$ Span of spring in inches.
$B =$ Breadth of plates in inches.
$T =$ Thickness of plates in sixteenths of an inch.
$N =$ Number of plates.
$D =$ Deflection in inches per ton of load.
$L =$ Safe load on spring in tons.

$$L = \frac{BT^2N}{11\cdot3S}. \qquad N = \frac{11\cdot3SL}{BT^2}. \qquad D = \frac{\cdot14S^3}{T^3BN}.$$

Number of Revolutions per Mile with Driving Wheels of different Diameters.

Diam. of wheel	2 ft.	$2\frac{1}{2}$ ft.	3 ft.	$3\frac{1}{2}$ ft.	4 ft.	$4\frac{1}{2}$ ft.	5 ft.
Revs. per mile	840	672	560	480	420	373	336
Diam. of wheel	$5\frac{1}{2}$ ft.	6 ft.	$6\frac{1}{2}$ ft.	7 ft.	8 ft.	9 ft.	10 ft.
Revs. per mile	$305\frac{1}{2}$	280	$258\frac{1}{2}$	240	210	187	168

Speed of Pistons.

D = Diameter of driving wheels in feet.
S = Stroke of engine in feet.
M = Miles per hour travelled by engine.
P = Speed of piston in feet per minute.

$$P = \frac{56 \cdot 0225\, S\, M}{D}.$$

An ordinary speed of piston is about 900 feet per minute.

Diameter of Driving Wheels in feet.	Speed of Piston in Feet per Minute at 60 Miles per Hour.				
	Stroke in inches.				
	18	20	22	24	26
3	1681	1867	2054	2241	2427
$3\frac{1}{2}$	1440	1600	1760	1921	2081
4	1260	1400	1540	1681	1821
$4\frac{1}{2}$	1120	1245	1369	1494	1618
5	1008	1120	1232	1345	1457
6	840	933	1027	1120	1214
7	720	800	880	960	1040
8	630	700	770	840	910
10	504	560	616	672	728

Rule for the Centre of Gravity of Locomotives.

C = Horizontal distance line of centre of gravity from driving axle.
L = Load on leading wheels.
T = Load on trailing wheels.
l = Distance of leading axle from driving axle.
t = Distance of trailing axle from driving axle.
B = Length of wheel base.
W = Total weight of engine.

$C = \frac{L\,l - T\,t}{W}$ measured towards leading axle.

If $T\,t$ exceeds $L\,l$, then

$C = \frac{T\,t - L\,l}{W}$ measured towards the trailing axle.

This rule applies to six-wheeled engines when the driving wheel is placed between the leading and trailing wheels. In four-wheeled engines, if L exceeds T, the horizontal distance of the centre of gravity measured from the *trailing* axle $= \frac{L\,B}{W}$. If T exceeds L, the distance measured from the *leading* axle $= \frac{T\,B}{W}$. If $T = L$, the centre of gravity is half-way between the two axles.

Consumption of Oil on Railways.

In America the consumption of oil is $\frac{1}{12}$th to $\frac{1}{15}$th of a pint per train mile.

Twenty pints of oil lubricate 8 journals of carriages 5000 miles, or 1 pint to 250 miles.

LOCOMOTIVES—*continued.*

(FRENCH PRACTICE.)

D = Diameter of cylinder.
A = Area of one cylinder.
H = Heating surface.
d = Diameter of tubes.

$D = \cdot 0416 \sqrt{H}.$
$A = \cdot 00136\ H.$

Stroke	=	1·57 D.
Length of connecting rod	=	3·84 D.
Ditto slide-valve = ·68 D	=	$\cdot 03 \sqrt{H}$.
Breadth of ditto = ·82 D	=	$\cdot 04 \sqrt{H}$.
Surface of ditto = ·59 A	=	·0012 H.
Angle of advance of slide	=	30°
Lineal advance	=	·013 D.
Inside cover of slide-valve	=	·012 D.
Outside cover	=	·065 D.
Diameter of eccentrics ..	=	·15 D.
Steam-port area	=	·071 A.
Length of port to width	=	·91.
Area of exhaust-pipe ..	=	·14 A.
Diameter of steam-pipe ..	=	·0002 H.
Area of regulator-opening	=	·00015 H.
Ditto of blast-pipe	=	·0002 H.
Ditto of nozzle of ditto ..	=	·00017 H.
Length of fire-grate ..	=	$\cdot 114 \sqrt{H}$.
Width of ditto	=	$\cdot 114 \sqrt{H}$.
Area of ditto	=	·013 H.

Locomotives (French Practice)—*continued.*

Height from fire-grate to lowest row of tubes	$= \cdot 08 \sqrt{H}$.
Internal diameter of tubes	$= 1\frac{1}{2}$ to $1\frac{3}{4}$ in.
Number of tubes	$= \cdot 0033 \dfrac{H}{2d}$.
Length of tubes	$= 87\,d$.
Thickness of metal in tubes ..	= 14 B.W.G.
Heating surface in fire-box ..	$= \cdot 08$ H.
Ditto in tubes	$= \cdot 92$ H.
Total	= H.
Total tube area	$= \cdot 00269$ H.
Width of fire-box water-space ..	$= 3\frac{1}{4}$ ins.
Distance of fire-box stay-bolts apart	= 4 ins.
Diameter of stay-bolts	$= \frac{7}{8}$ in.
Inside diameter of boiler	$= \cdot 124 \sqrt{H}$.
Length of boiler	$= \cdot 84\,d$.
Thickness of boiler-plate	$= \cdot 0013 \sqrt{H}$.
Ditto outer fire-box plate	$= \cdot 0014 \sqrt{H}$.
Ditto tube-plate (fire-box end) ..	$= \cdot 0024 \sqrt{H}$.
Area of one safety-valve	$= \cdot 0001$ H.
Diameter of pump-plunger ..	$= \cdot 0028 \sqrt{H}$.
Stroke of ditto	$= 4\frac{3}{4}$ inches.
Diameter of clack-valve opening	$= \cdot 0058 \sqrt{H}$.
Ditto suction-pipe	$= \cdot 0058 \sqrt{H}$.

	A	B	C	D	E	F	G	H		
	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.		
1	9½	10½	12	13	13½	16	17	17	1	Diameter of cylinder, inches.
2	Tank	Tank	Tan :	—	Mixed	Mixed	Mixed	Tank	2	Description .. ..
3	out	out	out	out	out	out	out	in	3	Outside or inside cylinders..
4	Bissell	—	—	—	—	Bogie	—	Bogie	4	
5	4	6	4	4	6	4	4	4	5	No. of wheels coupled.. ..
6	3 6	3 6	3 6	3 6	3 3⅜	5 6	4 8½	4 8½	6	Gauge of railway .. .. ..
										BOILER.
7	8 5⅜	9 2	8 0	9 8	9 2¾	9 7½	11 1⅜	10 6	7	Length .. ..
8	2 10⅝	2 11¼	3 0	3 5	3 2¾	4 0	4 2	4 2	8	Diameter .. ..
9	⅜	⅜	⅜	⅜	⅜	$\frac{7}{16}$	½	½	9	Thickness of plate .. ..
										OUTSIDE FIRE-BOX.
10	3 4	4 1	3 4	4 8	5 9	4 8	4 1¾	5 6	10	Length .. ..
11	2 11½	3 4¼	3 3½	3 6⅝	3 6¾	4 3⅝	4 4	4 4	11	Breadth at top .. .. ..
12	2 11⅜	2 11¼	2 10½	3 1	2 10½	4 3⅝	4 0	4 0½	12	Ditto at bottom .. ..
13	1 5¾	—	—	1 9$\frac{5}{16}$	—	—	—	2 2	13	Height above centre of boiler
14	2 8¾	1 5¾	1 4⅞	2 11	1 11⅛	2 4$\frac{13}{16}$	2 2¼	5 1⅞	14	Depth below " front
15	2 1¾	—	—	2 4	—	—	—	4 6⅞	15	" " back
16	$\frac{7}{16}$	⅜ to ⅝	$\frac{7}{16}$ to ⅝	$\frac{7}{16}$	$\frac{7}{16}$ to ½	$\frac{9}{16}$ to ½	½ to ⅞	½	16	Thickness of plate .. ..
										INSIDE FIRE-BOX.
17	2 10$\frac{7}{16}$	3 8	2 10$\frac{1}{16}$	4 2⅛	5 3	4 1	3 6	4 9$\frac{13}{16}$	17	Length at fire-grate .. ..
18	2 5¾	2 5½	2 4¾	2 7⅛	2 3½	3 8⅝	3 4½	3 4½	18	Breadth at ditto .. .. ..
19	3 3½	3 2½	3 3½	3 8	3 9½	4 9⅜	4 10	5 11⅞	19	Depth at front .. .. ..
20	2 8½	2 5	3 3½	3 1	2 5	4 9⅜	4 10	5 4⅞	20	Ditto at back .. .. ..

LOCOMOTIVES. (From actual Practice.)

	J	K	L	M	N	O	P	Q	R	
	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	
1	17	17	$17\frac{1}{2}$	$17\frac{1}{2}$	$17\frac{1}{2}$	$17\frac{1}{2}$	18	18	18	1
2	Express	Express	Tank	Goods	Pass'ger	Express	Goods	Goods	—	2
3	inside	inside	inside	inside	outside	inside	inside	outside	inside	3
4	—	Single	Bogie	—	Bogie	Bogie	—	—	—	4
5	4	—	4	6	4	4	6	6	4	5
6	4 $8\frac{1}{2}$	4 $8\frac{1}{2}$	4 $8\frac{1}{2}$	4 $8\frac{1}{2}$	4 $8\frac{1}{2}$	4 $8\frac{1}{2}$	4 $8\frac{1}{2}$	4 $8\frac{1}{2}$	4 $8\frac{1}{2}$	6
7	10 $4\frac{1}{2}$	10 1	10 6	10 6	10 6	10 2	10 $3\frac{1}{2}$	14 5	10 6	7
8	4 3	4 4	4 1	4 0	4 2	4 $2\frac{1}{8}$	4 4	4 2	4 2	8
9	$\frac{7}{16}$	$\frac{9}{16}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{7}{16}$	$\frac{9}{16}$	$\frac{1}{2}$	$\frac{1}{2}$	9
10	5 6	5 5	5 6	5 11	5 0	5 9	6 6	4 $10\frac{3}{4}$	5 6	10
11	4 4	4 $6\frac{3}{8}$	4 5	4 4	4 8	4 4	4 $7\frac{1}{2}$	4 4	4 3	11
12	4 0	4 1	4 1	4 $0\frac{1}{2}$	3 $11\frac{1}{4}$	3 11	4 1	4 0	4 0	12
13	2 2	2 $3\frac{3}{16}$	—	—	2 $7\frac{1}{4}$	2 2	2 $3\frac{3}{4}$	—	—	13
14	4 $10\frac{1}{2}$	5 6	4 $6\frac{1}{2}$	5 2	4 $4\frac{5}{8}$	5 2	5 $2\frac{3}{4}$	4 $7\frac{1}{2}$	4 8	14
15	4 $10\frac{1}{2}$	4 4	—	—	4 $1\frac{5}{8}$	5 2	3 $5\frac{3}{4}$	—	—	15
16	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{5}{8}$ to $\frac{11}{16}$	$\frac{1}{2}$ to $\frac{5}{8}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{1}{2}$ to $\frac{3}{4}$	$\frac{1}{2}$	16
17	4 $9\frac{7}{8}$	4 $8\frac{5}{8}$	4 11	5 $2\frac{13}{16}$	4 $3\frac{7}{8}$	5 $0\frac{7}{8}$	5 $9\frac{5}{8}$	4 3	4 $9\frac{3}{4}$	17
18	3 4	3 $4\frac{5}{8}$	3 6	3 $4\frac{1}{2}$	3 $3\frac{1}{4}$	3 3	3 $4\frac{5}{8}$	3 $4\frac{1}{2}$	3 4	18
19	5 9	6 5	5 $1\frac{1}{2}$	5 6	5 $3\frac{3}{8}$	6 0	6 $1\frac{3}{4}$	5 $2\frac{1}{2}$	4 11	19
20	5 9	5 3	4 $4\frac{1}{2}$	4 11	5 $0\frac{3}{8}$	6 0	4 $4\frac{3}{4}$	5 $2\frac{1}{2}$	4 5	20

	A $9\frac{1}{2}$	B $10\frac{1}{2}$	C 12	D 13	E $13\frac{1}{2}$	F 16	G 17	H 17		Diameter of cylinder.
										INSIDE FIRE-BOX—*continued.*
	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.		
21	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	21	Thickness of plate .. .. ..
22	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{13}{16}$	22	Ditto of tube-plate .. .. ..
23	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	1	$\frac{7}{8}$	$\frac{7}{8}$	1	$\frac{7}{8}$	23	Diameter of copper stays ..
24	$3\frac{7}{8} \times 4$	$3\frac{7}{8}$	4	$4\frac{1}{8} \times 3\frac{7}{8}$	4	4	4	$3\frac{15}{16} \times 4$	24	Distance of centres.. .. ..
										TUBES, &c.
25	8 $3\frac{1}{2}$	9 $5\frac{1}{2}$	8 $3\frac{3}{8}$	9 $11\frac{1}{2}$	9 $6\frac{3}{4}$	10 0	10 10	10 $10\frac{5}{8}$	25	Length between plates .. ..
26	$1\frac{5}{8}$	$1\frac{3}{4}$	$1\frac{3}{4}$	$1\frac{5}{8}$	$1\frac{5}{8}$	$1\frac{3}{4}$	$1\frac{3}{4}$	$1\frac{3}{4}$	26	Diameter outside .. .. ..
27	$2\frac{1}{4}$	$2\frac{3}{8}$	$2\frac{3}{8}$	$2\frac{1}{4}$	$2\frac{1}{4}$	$2\frac{1}{2}$	$2\frac{3}{8}$	$2\frac{3}{8}$	27	Distance of centres .. .. ..
28	32	$42\frac{1}{2}$	$39\frac{1}{2}$	47	$62\frac{3}{4}$	$90\frac{3}{8}$	78	$104\frac{1}{2}$	28	Fire-box area, square feet ..
29	360	$446\frac{1}{4}$	$381\frac{3}{4}$	$618\frac{1}{2}$	590	$925\frac{1}{2}$	$992\frac{1}{2}$	1092	29	Tube surface, ,, ,, ..
30	392	$482\frac{3}{8}$	$416\frac{1}{2}$	$665\frac{1}{2}$	644	1007·35	106[illegible]$\frac{1}{4}$	$1196\frac{1}{2}$	30	Total heating surface, sq. ft.
31	7·16	9	6·78	10·82	11·83	15·13	11·79	16·1	31	Fire-grate area, square feet ..
										CHIMNEY, &c.
32	9 6	10 $5\frac{1}{2}$	10 0	10 $11\frac{7}{8}$	10 10	13 6	12 $3\frac{1}{4}$	13 2	32	Height from rails .. .. ..
33	$10\frac{5}{8}$	11	1 $1\frac{1}{8}$	1 1	1 2	1 $4\frac{3}{4}$	1 5	1 3	33	Diameter at top .. .. ..
34	$11\frac{1}{8}$	11	$11\frac{1}{2}$	1 0	1 1	1 2	1 3	1 4	34	Ditto at bottom .. .. ..
35	$2\frac{7}{8}$	$2\frac{1}{2}$	3	$3\frac{1}{4}$	$3\frac{1}{2}$	$3\frac{1}{2}$	$5\frac{3}{8}$	$4\frac{1}{2}$	35	Diameter of blast-pipe .. ..
36	$5\frac{1}{4}$	$8\frac{1}{4}$	1 4	1 $1\frac{3}{4}$	1 3	1 6	1 1	1 $4\frac{1}{2}$	36	Depth of ditto below smoke-box
										PUMPS.
37	—	—	—	—	—	—	—	—	37	Diameter of plunger .. ..
38	—	—	—	—	—	—	—	—	38	Stroke of ditto .. ..
39	—	—	—	—	—	—	—	—	39	Diameter of waterway .. ..

	J 17	K 17	L $17\frac{1}{2}$	M $17\frac{1}{2}$	N $17\frac{1}{2}$	O $17\frac{1}{2}$	P 18	Q 18	R 18	
	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	
21	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{1}{2}$	$\frac{1}{2}$	21
22	$\frac{7}{8}$	$\frac{7}{8}$	1	$\frac{13}{16}$	$\frac{7}{8}$	$\frac{13}{16}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{3}{4}$	22
23	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	1	Iron $1\frac{1}{8}$	23
24	4×4	$4 \times 4\frac{3}{16}$	4	4	$4 \times 4\frac{1}{16}$	$4 \times 3\frac{7}{8}$	$4 \times 4\frac{1}{16}$	4	4	24
25	10 $8\frac{1}{2}$	10 $5\frac{5}{16}$	10 $10\frac{5}{8}$	10 $10\frac{5}{8}$	10 $10\frac{1}{8}$	10 6	10 $7\frac{13}{16}$	14 $1\frac{3}{8}$	10 $9\frac{1}{2}$	25
26	$1\frac{3}{16}$	$1\frac{3}{4}$	$1\frac{3}{4}$	$1\frac{3}{4}$	$1\frac{3}{4}$	$1\frac{3}{4}$	$1\frac{3}{4}$	2	$1\frac{1}{2}$	26
27	$2\frac{3}{16}$	$2\frac{1}{2}$	$2\frac{1}{2}$	$2\frac{3}{8}$	$2\frac{1}{2}$	$2\frac{1}{2}$	$2\frac{1}{2}$	$2\frac{3}{4}$	$2\frac{1}{8}$	27
28	100	86	94	101	84	107	94	$92\frac{1}{2}$	$98\frac{1}{4}$	28
29	1108	957	$967\frac{1}{2}$	1112	$1023\frac{1}{2}$	962	1005	990	1059	29
30	1208	1043	$1052\frac{1}{2}$	$1201\frac{3}{4}$	$1107\frac{1}{2}$	1069	1099	1073	1144	30
31	16·1	15·97	17·18	17·63	14·14	16·5	19·6	14·32	15·91	31
32	13 2	13 0	13 0	13 $0\frac{1}{2}$	12 5	13 $3\frac{7}{8}$	13 0	12 11	13 0	32
33	1 7	1 5	1 $6\frac{1}{4}$	1 3	1 $2\frac{3}{8}$	1 6	1 6	1 5	1 6	33
34	1 4	1 4	1 3	1 4	1 $3\frac{1}{4}$	1 $4\frac{1}{2}$	1 5	1 3	1 5	34
35	$4\frac{3}{4}$	$4\frac{3}{4}$	$4\frac{7}{8}$	$4\frac{5}{8}$	$4\frac{1}{2}$	variable	$4\frac{3}{4}$	5	$4\frac{3}{4}$	35
36	1 $5\frac{3}{4}$	1 5	1 $6\frac{3}{4}$	1 $4\frac{1}{2}$	1 $4\frac{7}{16}$	1 $6\frac{9}{16}$	1 $5\frac{1}{4}$	1 5	1 $8\frac{3}{4}$	36
37	—	$2\frac{1}{8}$	—	—	—	—	$2\frac{1}{8}$	—	—	37
38	—	2 0	—	—	—	—	2 2	—	—	38
39	—	$2\frac{1}{8}$	—	—	—	—	$2\frac{1}{8}$	—	—	39

	A 9½	B 10½	C 12	D 13	E 13½	F 16	G 17	H 17		Diameter of cylinder.
	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.		**INJECTORS.**
40	2	2	2	2	2	2	2	2	40	Number of injectors ..
41	6	6	6	6	7	7 & 8	8	9	41	Gauge in millimètres ..
										SAFETY-VALVES.
42	2	2	2	2	2	2	2	2	42	Number .. ..
43	2	2⅞	0 2⅝	2	2½	2½	2½	3⅜ & 2	43	Diameter .. ..
										CYLINDERS.
44	4 4	4 11¾	5 0	6 4⅛	5 6¼	6 9	6 2	2 4	44	Distance of centres at front
45	1 6	1 6	1 6	1 8	1 8	2 0	1 10	2 0	45	Stroke .. ..
46	1⅝	1¾	1⅞	2⅛	2⅛	2⅜	2⅝	2¾	46	Diameter of piston-rod
47	2¾	2¾	3¼	2¾	3½	3	4	3	47	Depth of piston .. ..
										PORTS.
48	6	7	10½	10	11½	1 2	1 1	1 3	48	Breadth of ports .. ..
49	1	1	1	1⅛	1¼	1¼	1½	1⅜	49	Length of steam-ports ..
50	1¾	1¾	2½	2¼	3	3¼	3	3½	50	Ditto of exhaust .. ..
51	2¼	2¼	2½	3	2¾	3½	3	4	51	Diameter of steam-pipe..
										SLIDES.
52	2⅞	2⅞	3¼	3½	3⅝	3⅝	5½	3⅝	52	Travel .. ..
53	⅛	⅛	5/32	⅛	⅛	5/32	7/16	3/16	53	Lead .. ..
54	11/16	11/16	¾	13/16	⅞	15/16	1¼	⅞	54	Steam overlap.. .. ..
55	8	5⅞	6	7 5/16	7½	7⅝	9 7/16	8⅞	55	Lift of links .. .. ..
										ECCENTRICS.
56	9½	11½	11	1 0¾	1 1	1 3	1 3¼	1 3¼	56	Diameter of sheaves ..

	J 17	K 17	L 17½	M 17½	N 17½	O 17½	P 18	Q 18	R 18	
	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	
40	2	—	2	2	2	2	—	2	1	40
41	8	—	7 & 8	9	8	9	—	8	10	41
42	3	2	2	2	2	2	2	2	2	42
43	4 & 2	2½	3	3⅜	2½	3½	2½	2½	2½	43
44	2 4½	2 3	2 4	2 4	6 2½	2 4	2 3	6 6	2 4½	44
45	2 0	2 0	2 2	2 2	2 2	2 2	2 2	2 0	2 2	45
46	2⅞	2¾	2¾	2¾	2¾	2¾	3	2⅝	2¾	46
47	4	4	4	3	3½	3¼	4	4	3¼	47
48	1 1	1 3	1 3	1 3½	1 1½	1 2	1 4	1 3	1 4	48
49	1⅛	1½	1¼	1⅜	1½	1½	1⅝	1⅝	1½	49
50	3½	$\frac{3}{16}$	3	3½	3	3¼	3¼	3¼	3	50
51	4	3	3⅞	4	4	4½	3¼	3	3¾	51
52	$4\frac{9}{16}$	$4\frac{3}{16}$	4	3½	$4\frac{7}{16}$	3⅞	$4\frac{5}{16}$	5⅛	4⅜	52
53	$\frac{3}{16}$	⅛	⅛	⅛	⅛	$\frac{3}{32}$	⅛	⅛	⅛	53
54	1¼	1	1	⅞	$1\frac{1}{16}$	1	1	1¼	1	54
55	$10\frac{9}{16}$	9½	9¼	$5\frac{15}{16}$	$10\frac{7}{16}$	8	9½	10	9	55
56	1 4¼	1 4¾	1 4	1 3¼	1 4	1 4¼	1 4¾	1 3¼	1 3¼	56

	A $9\frac{1}{2}$	B $10\frac{1}{2}$	C 12	D 13	E $13\frac{1}{2}$	F 16	G 17	H 17		Diameter of cylinder.
	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.		ECCENTRICS—*continued.*
57	$1\frac{7}{8}$	$1\frac{3}{4}$	$1\frac{7}{8}$	$2\frac{1}{8}$	$2\frac{1}{4}$	$2\frac{3}{4}$	$2\frac{1}{4}$	$3\frac{1}{4}$	57	Width of sheaves .. ..
58	3	$4\frac{7}{8}$	4	$5\frac{1}{2}$	6	$6\frac{1}{4}$	$5\frac{1}{2}$	$5\frac{3}{4}$	58	Throw of eccentrics ..
										MOTION BARS.
59	2	2	2	1	1	1	2	4	59	No. to each cylinder ..
60	$3\frac{1}{2}$	$3\frac{1}{2}$	3	$3\frac{1}{2}$	$3\frac{1}{2}$	$4\frac{1}{2}$	5	$2\frac{3}{4}$	60	Breadth .. ..
61	$1\frac{3}{8}$	$1\frac{5}{8}$	$1\frac{1}{2}$	$2\frac{3}{8}$	$2\frac{1}{4}$	$2\frac{1}{4}$	$2\frac{3}{4}$	2	61	Thickness .. .. ..
62	—	$9\frac{1}{4}$	$9\frac{1}{4}$	—	—	—	$11\frac{1}{2}$	$6\frac{1}{2}$	62	Distance apart .. ..
63	$9\frac{3}{4}$	10	12	11	11	12	12	10	63	Length of block .. ..
64	$9\frac{1}{4}$	$\frac{3}{4}$	—	—	—	—	—	$3\frac{1}{4}$	64	Thickness of ditto .
65	$1\frac{3}{4}$	—	—	$2\frac{1}{4}$	—	—	—	2	65	Diam. of slide-block pin
66	$1\frac{3}{4}$	2	$2\frac{1}{4}$	$2\frac{1}{4}$	$2\frac{1}{2}$	$2\frac{3}{4}$	$2\frac{3}{4}$	3	66	Do. connecting-rod pin
67	2	$2\frac{1}{8}$	2	$2\frac{1}{8}$	$2\frac{1}{4}$	$2\frac{5}{8}$	3	$2\frac{5}{8}$	67	Length of ditto .. ..
										WHEELS.
68	1 6	3 0	2 6	3 9	3 6	2 9	3 8	5 6	68	Diameter of leading ..
69	3 0	3 0	—	3 0	3 6	5 $0\frac{1}{2}$	6 2	3 0	69	Ditto of trailing .. ..
70	3 0	3 0	2 6	3 9	3 6	5 $0\frac{1}{2}$	6 2	5 6	70	Ditto of driving .. ..
71	11 7	10 6	5 6	11 0	11 0	19 3	15 2	21 9	71	Wheel base .. .. ..
										AXLES.
72	$5\frac{1}{4}$	$5\frac{1}{4}$	6	$5\frac{3}{4}$	$5\frac{1}{2}$	$7\frac{3}{4}$	7	$8\frac{1}{16}$	72	Diameter at wheels ..
73	$4\frac{1}{2}$	$4\frac{1}{2}$	5	5	$4\frac{7}{8}$	6	7	$6\frac{3}{4}$	73	Ditto at middle .. ..
74	$4\frac{1}{2}$	$4\frac{1}{2}$	—	5	$7\frac{3}{8}$	$6\frac{3}{4}$	7	7	74	Ditto of journal .. ..
75	$5\frac{3}{4}$	$5\frac{3}{4}$	7	8	$6\frac{1}{2}$	8	$7\frac{15}{16}$	$7\frac{1}{4}$	75	Length of ditto .. ..

LOCOMOTIVES—*continued.*

	J 17		K 17		L 17½		M 17½		N 17½		O 17½		P 18		Q 18		R 18		
	ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.	
57		3		2⅛		2⅞		3		2¾		2¾		2⅝		2¾		2¾	57
58		6½		6½		6¼		5¾		6½		6½		6½		5½		6½	58
59	4		4		4		4		2		4		4		1		4		59
60		2½		3¾		2¾		2¾		5		3		3¼		5		2¾	60
61		1¾		1¾		2		2		2½		2¼		1¾		2½		2½	61
62		7		5¾		3		3¼		—		6⅞		6		—		3	62
63		10	1	0	1	2		10	1	2	1	2	1	0	1	3		10¼	63
64		3		3¾		—		—		11¼		3⅜		3¾		¾		—	64
65		2		2¼		1⅝		2		3		2		2¼		—		2	65
66		3		3¼		3		3		3		3		3¼		2¾		3	66
67		2 15/16		3		3		2⅝		3		2¾		2 15/16		3		2⅞	67
68	4	6¼	4	6	5	8	4	10	3	0½	3	6	5	0	5	2	5	7½	68
69	7	0¼	4	6	3	0½	4	10	6	1	6	6	5	0	5	2	3	7½	69
70	7	0¼	7	0	5	8	4	10	6	1	6	6	5	0	5	2	5	7½	70
71	16	1	15	6	22	7	16	6	20	6	21	0½	15	3	11	0	14	8	71
72		7 13/16		8¼		8½		8		8½		9 1/16		8¼		7		8	72
73		6½		7½		7		6¾		6½		7		7½		7		7	73
74		7		8		7½		7		7		7½		8		7		7	74
75		7¾		7½		7		7¼		9		7½		7½		9½		7	75

	A 9½	B 10½	C 12	D 13	E 13½	F 16	G 17	H 17		Diameter of cylinder.
	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.		CRANK.
76	2¾	2½	3	2	2⅝	4	3½	7	76	Diameter of crank-pin
77	2½	$2\frac{11}{16}$	2¾	3	2½	4	3½	4	77	Length of ditto .. ..
										CONNECTING ROD.
78	3 × 1⅛	3·75	4·4	3¼×1⅜	4·31	4·96	5·68	4¾×1¾	78	Section at large end ..
79	2¼×1⅛	3·125	2·98	2½×1⅜	3·0	2·84	4·46	3½×1¾	79	Ditto at small end ..
80	4 3	4 7	5 3	4 10	4 11	5 9	5 2	6 5⅝	80	Length .. ..
81	2¼	3	3½	3½	3	3	4¼	3¼	81	Diam. of side-rod pins..
82	$2\frac{5}{16}$	$3\frac{11}{16}$	2⅛	2⅝	2½	3	2½	3½	82	Length of ditto .. ..
										ECCENTRIC-RODS.
83	2 10	4 2	3 5½	3 9	3 9	4 3	3 9	4 7⅞	83	Length (centre) ..
84	2½ × ¾	—	—	3×¾	—	—	—	3½×1	84	Section at large end ..
85	—	1·567	1·054	—	1·5	1·75	1·8	—	85	Ditto at small end ..
										TENDER.
86	300	450	500	1200	2350	1400	1840	970	86	Contents of tank, gals...
87	⅛	$\frac{3}{16}$	$\frac{3}{16}$	¼	¼	¼	¼ & $\frac{5}{16}$	$\frac{3}{16}$	87	Thickness of plate ..
88	Tank	Tank	Tank	6 0	7 10½	11 0	11 5½	Tank	88	Wheel base .. .. ..
89	—	—	—	2	3	3	3	—	89	Number of axles .. ..
90	—	—	—	3 0	2 $0\frac{7}{16}$	3 6½	3 8	—	90	Diameter of wheels ..
91	—	—	—	4	$3\frac{15}{16}$	4⅞	5¾	—	91	Diam. of axles, middle
92	—	—	—	3½	2¾	3¾	4½	—	92	Ditto ditto journal ..
93	—	—	—	8	6¼	9	11	—	93	Length of journal ..
94	—	—	—	$5\frac{1}{16}$	3¾	5¼	5⅞	—	94	Diam. of axle at wheels
95	—	—	—	5 0⅝	4 7⅞	7 3	6 3	—	95	Centres of bearings apart

LOCOMOTIVES—*continued.*

	J 17	K 17	L 17½	M 17½	N 17½	O 17½	P 18	Q 18	R 18	
	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	
76	7	8	7½	7	3½	7¾	8	3½	7½	76
77	3⅞	4	4	3⅞	4	4	4	3½	4	77
78	4¾ × 1½	5 × 2	7·0	7·5	4 × 1¾	5 × 1⅞	5 × 2	7·0	7·0	78
79	3½ × 1½	3½ × 2	4·8	5·5	3 × 1¾	3½ × 1⅞	3½ × 2	5·5	3·27	79
80	5 7½	6 6	6 2	6 2¾	6 1½	5 10	6 6	5 3	6 1	80
81	3¼	—	4	3¾	4½	4	4¼	4½	4	81
82	3 9/16	—	4 5/16	4	3	4	4½	2⅜	3½	82
83	5 6½	5 6	4 10	4 3⅞	5 1	4 3	4 7	3 7	5 6	83
84	4 × ⅞	3½ × 13/16	—	—	3½ × ⅞	4 × 1⅛	3½ × 13/16	—	—	84
85	—	—	1·75	2·95	—	—	—	2·95	2 0	85
86	2200	2400	1100	2350	1950	2550	2400	1840	1800	86
87	¼	¼	¼	3/16 to 5/16	3/16	¼	¼	5/16 to ¼	¼	87
88	12 3	12 0	Tank	13 0	11 0	12 0	12 0	11 5½	11 7½	88
89	3	3	—	3	3	3	3	3	3	89
90	3 8¼	4 0	—	4 0	3 7½	3 9	4 0	3 8	3 7½	90
91	5¾	6	—	5¼	5⅝	6	6	5¾	5	91
92	5	5	—	4¾	5	5¼	5	4¼	4¼	92
93	10	8	—	9	10	9½	8	11	9⅞	93
94	6¾	7	—	6½	6⅞	6¾	7	5⅞	6	94
95	6 10	6 2	—	6 3	*6 3	6 4	6 2	6 3	6 2¾	95

	A 9½	B 10½	C 12	D 13	E 13½	F 16	G 17	H 17		Diameter of cylinder.
	tns. cwt. qrs.	tns. cwt. qrs.	tns. cwt. qrs.	tns. cwt. qrs.	tns. cwt. qrs.	tns. cwt. qrs.	tns. cwt. qrs.	tns. cwt. qrs.		WEIGHT (in working trim).
96	3 7 3	6 18 2	7 8 2	6 17 2	6 19 0	12 17 2	10 16 3	13 9 1	96	Weight on leading wheels
97	5 12 2	6 2 0	—	6 19 0	6 18 0	11 8 0	12 19 1	14 12 2	97	Ditto on driving wheels ..
98	5 15 3	5 16 0	8 15 2	4 16 0	6 10 2	11 5 0	11 16 3	15 8 0	98	Ditto on trailing wheels ..
99	14 16 0	18 16 2	16 4 0	18 12 2	20 7 2	36 0 2	37 12 3	43 9 3	99	Total weight .. .. ..
	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.		
100	3 3½	3 3½	3 3½	3 3¼	3 0½	5 3	4 5½	4 5⅝	100	Distance of inside of wheels
101	centre	centre	2 3½	centre	centre	6 5	5 9	5 8	101	Ditto of centres of buffers
102	2 4½	2 4½	2 0	2 6	1 10	3 5¾	3 6	3 4	102	Height of ditto ditto above rails .. ..

BALANCING LOCOMOTIVES. (Rankine.)

The centre of gravity of the counterbalance weight should be in the prolongation of the line that bisects the angle formed by the two cranks, or at an angle of 135° with each crank.

The formula can only give approximate results, as there are other disturbing influences; and the engine should be further adjusted by suspending it by means of chains or ropes from the corners of the framing, leaving it free to oscillate, and the weights should be increased or diminished until the oscillation of the engine working at speed is reduced to a minimum. The suspension should be on springs, so as to allow vertical as well as horizontal motion. The balance is sometimes facilitated by placing the driving wheels in the lathe centres, so that they may revolve freely, and then attaching in position the connecting rod and other moving parts.

	J 17			K 17			L 17½			M 17½			N 17½			O 17½			P 18			Q 18			R 18			
	tns.	cwt.	qrs.	tns.	cwt.	qrs.	tns.	cwt.	qrs.	tns.	cwt.	qrs.	tns.	cwt	qrs.	tns.	cwt.	qrs.	tns.	cwt.	qrs.	tns.	cwt.	qrs.	tns.	cwt.	qrs.	
96	12	8	0	12	9	0	13	15	1	12	17	1	13	15	0	14	19	2	12	5	0	12	12	0	12	16	0	96
97	14	3	0	15	4	0	15	2	2	11	4	2	13	8	0	13	16	0	13	8	0	13	3	2	11	14	1	97
98	12	18	0	10	5	0	20	13	3	11	1	2	12	7	0	14	1	0	12	9	0	11	8	0	7	8	0	98
99	39	9	0	38	8	0	49	11	2	35	3	1	39	10	0	42	16	2	38	2	0	37	3	2	32	18	1	99
	ft.	in.		ft	in.		ft.	in.		ft.	in.		ft.	in.		ft.	in.		ft.	in.		ft.	in.		ft.	in.		
100	4	5⅝		4	5⅝		4	5⅝		4	5⅝		4	5½		4	5⅝		4	5½		4	5½		4	5½		100
101	5	9		5	8		5	9		5	8		5	8		5	8		5	8		5	9		5	8		101
102	3	4		3	5½		3	4		3	4		3	6		3	5		3	5½		3	5		3	6		102

BALANCING LOCOMOTIVES—*continued.*

W = Accumulated weight of moving parts acting on crank. w = Weight of counterbalance.
R = Radius of centre of crank pin. r = Radius of centre of gravity of counterbalance weight.
D = Distance of centre of crank from centre of engine. d = Distance of the centre of gravity of counterbalance weight from centre of engine.

$$w = \frac{W\,R}{r}\sqrt{\frac{D^2 + d^2}{2\,d^2}}.$$

THICKNESS OF METAL IN CYLINDERS.

D = Diameter of cylinder in inches.
P = Pressure of steam in lbs. per square inch.
T = Thickness of metal in inches.

$$T = \frac{D\,P}{4000} + \tfrac{1}{2}.$$

Principal Dimensions of High-pressure Compound

	173	243	296	465	516	572	1016	Indicated Horse-power.
1	14	21	21	28	25	29	38	Diameter of high-pressure cylinder in inches ..
2	25	36	38½	48	50	56	64	Diameter of low-pressure cylinder in inches ..
3	1	1	1	1	1	1	1	Number of high-pressure cylinders .. .. ..
4	1	1	1	1	1	1	1	Number of low-pressure cylinders .. .. ..
5	1 4½	1 4	1 6	1 6	3 0	2 6	2 0	Length of stroke in feet and inches .. .. ..
6	161	152	127	133	60	56	104	Number of revolutions per minute, on trial ..
7	7 0	6 1½	8 6	9 0	14 6	14 9	13 0	Diameter of propeller in feet and inches .. ..
8	6 6	9 3	7 9	9 3	17 0	15 0	12 0	Pitch of propeller .. ..
9	—	—	—	—	—	—	—	Diameter of paddle-wheels to centre of floats .
10	—	—	—	—	—	—	—	Length of floats .. ..
11	—	—	—	—	—	—	—	Breadth of floats .. ..
12	1	1	1	1	1	1	1	Number of propellers .. ..
13	3½	4½	5½	6	7	7½	10	Diameter of main steam-pipe in inches .. ..
14	10	20	20	38	40·25	43·75	75	Area of high-pressure steam-ports in sq. inches
15	30	60	50	63	101·50	119	157·50	Area of low-pressure " "
16	15·75	40	60	77·40	115	150	120	Area of high-pressure eduction-ports .. ..
17	55	60	75	126	145	204	262·50	Area of low-pressure " .. ..
	S. a.	S. a.	S. a.	D. a.	S. a.	S. a.	D. a.	Single acting (S. a.) or double acting (D. a.) ..
18	14	18	18	11¼	24	27	16	Diameter of air-pump in inches .. ..
19	6	8	9	1 6	1 5	1 3	2 0	Length of stroke of air-pump in feet and inches
20	1	1	1	1	1	1	1	Number of air-pumps .. ..
21	1⅞	2¼	2¼	2	3	3¼	2⅝	Diameter of air-pump rod in inches .. .. ..
22	B	B	B	B	B	B. cased	B	Air-pump rod, brass or iron or brass cased ..

Marine Engines. (Manufactured by Messrs. Maudslay, Sons, and Field.)

	1189	1258	1305	1319	2334	3388	3470	3666	4130	5429	7713	
1	30	36	46	38	34	62	41	42	43	48	41	1
2	70	68	82	70	75	112	75	78	80	83	75	2
3	1	1	1	1	2	1	2	2	2	2	4	3
4	1	1	1	1	2	1	2	2	2	2	4	4
5	4 0	3 9	5 0	4 0	2 9	5 0	4 3	5 0	4 6	5 0	3 0	5
6	58	62	30½	61¼	96·13	54	62	52	—	57¼	97	6
7	16 0	16 0	—	16 0	15 0	19 0	19 0	22 0	19 8	23 6	16 3½	7
8	21 0	19 0	—	20 0	15 6	30 0	28 0	30·3	27 6	30 6	19 11	8
9	—	—	19 0	—	—	—	—	—	—	—	—	9
10	—	—	8 6	—	—	—	—	—	—	—	—	10
11	—	—	3 4	—	—	—	—	—	—	—	—	11
12	1	1	2	1	1	1	1	1	1	1	2	12
13	9	—	7½	10	12	17	13	14	14	66	22	13
14	65·50	80	80	80	75	220	93	104	104	123·50	112	14
15	240	210	112	220	250	594·50	270	299	299	338	299	15
16	112·50	240	240	240	120	308	170·5	224	224	266	192	16
17	312	273	336	286	350	779	372·25	414	414	468	390	17
	S. a.	S. a.	S. a.	S. a.	D. a.	S. a.	S. a.	S. a.	S. a.	S. a.	S. a.	
18	30½	35	40	35	16	35	35	38	38	41	43	18
19	2 0	1 8	2 4	1 8	2 9	2 6	2 0	2 3	2 0	2 3	1 9	19
20	1	1	1	1	2	2	2	2	2	2	1 to each engine	20
21	3¾	4	trunk	4	2⅝	4⅞	4	4⅜	4⅜	4¾	hollow trunk	21
22	B. cased	B. cased	B	B. cased	B	B. cased	B. cased	B. cased	B. cased	B. cased	B	22

	173	243	296	465	516	572	1016	Indicated Horse-power.	
23	3¼	2⅛	2½	3½	3½	4	3⅜	Diameter of feed-pump plunger in inches ..	23
24	2¼	8	9	6	1 5	1 3	2 0	Length of stroke of feed-pump in feet and inches	24
25	2 8	2 8	3 4½	3 0	6 0	5 6	4 0	Length of connecting rod	25
26	2⅜	3¼	3⅝	4½	4¾	5⅛	6	Diameter of high-pressure piston-rods in inches	26
27	3⅛	3½	3⅝	4½	4¾	5⅛	6	Diameter of low-pressure piston-rods	27
28	1	1	1	1	1	1	1	Number of piston-rods to each cylinder	28
29	3	3½	3½	3¾	5	5	5	Stroke of high-pressure slide-valves in inches	29
30	4¼	3½	3½	3¾	5	5	5	Stroke of low-pressure slide-valves	30
31	1	1	1	1	1	1	1	Number of slide-rods to each cylinder	31
32	1¼	2	2⅛	2	2½	3	3¼	Diameter of high-pressure slide-rods in inches	32
33	1⅝	2	2⅛	2	2½	3	3¼	Diameter of low-pressure slide-rods	33
34	$\frac{13}{16}$	⅞	⅞	1⅛	1⅛	1¼	1⅛	Thickness of low-pressure cylinders in inches	34
35	¾	$\frac{15}{16}$	$\frac{15}{16}$	$1\frac{1}{16}$	1	1⅛	1⅛	Thickness of high-pressure cylinders ,,	35
36	none	none	none	1	none	1⅛	1¼	Thickness of high-pressure jackets	36
37	none	$\frac{15}{16}$	⅞	1	none	1⅛	1⅜	Thickness of low-pressure jackets	37
38	5¼	5¾	6½	6½	8¾	9¼	10¼	Diameter of crank-pin in inches	38
39	5	5½	6⅛	6½	9	9¼	11¼	Length of crank-pin	39
40	5	5¼	6¼	6½	8¾	9¼	9¾	Diameter of crank-shaft bearings	40
41	9¼	2 of 9½	6¼	1of 16 2of 13	1of 15 2of 13	12¼	2 of 18 2 of 13½	Length of crank-shaft bearing	41
42	660	514	898	830	1088	1015	1704	Number of tubes in surface condenser	42
43	⅝	⅝	⅝	⅝	⅝	¾	⅝	Diameter of tubes (inside) in inches	43

	1189	1258	1305	1319	2334	3388	3470	3666	4130	5429	7713	
23	$4\frac{1}{2}$	5	7	5	4	7	$6\frac{1}{2}$	7	7	$7\frac{1}{2}$	$7\frac{1}{2}$	23
24	2 0	1 8	1 6	1 8	2 9	2 6	2 0	2 3	2 0	2 3	1 6	24
25	8 0	7 6	—	8 0	5 9	10 0	8 6	10 0	9 0	10 0	5 6	25
26	$5\frac{1}{2}$	6	7	$6\frac{1}{4}$	$4\frac{3}{4}$	$10\frac{1}{2}$	6	6	$6\frac{1}{4}$	$7\frac{1}{4}$	$8\frac{3}{8}$	26
27	8	$6\frac{1}{2}$	8	$6\frac{3}{4}$	$5\frac{1}{2}$	12	$8\frac{3}{8}$	$8\frac{3}{4}$	$8\frac{3}{4}$	$9\frac{3}{4}$	$7\frac{5}{8}$	27
28	1	1	1	1	1 HP 2 LP.	1	1	1	1	1	1	28
29	4	7	$6\frac{1}{4}$	7	$6\frac{1}{2}$	7	$8\frac{1}{2}$	9	9	9	$6\frac{3}{4}$	29
30	8	7	$6\frac{1}{4}$	7	$7\frac{1}{8}$	10	$8\frac{1}{2}$	9	9	9	8	30
31	1	1	2	1	2	1	1	1	1	1	2	31
32	3	$3\frac{7}{8}$	2	$3\frac{7}{8}$	$1\frac{5}{8}$	$6\frac{1}{4}$	$2\frac{3}{4}$	3	3	$3\frac{1}{2}$	$2\frac{1}{2}$	32
33	$4\frac{1}{2}$	$3\frac{7}{8}$	2	$3\frac{7}{8}$	$2\frac{7}{8}$	$6\frac{1}{4}$	$4\frac{3}{4}$	5	5	$5\frac{1}{2}$	$3\frac{1}{4}$	33
34	$1\frac{3}{4}$	$1\frac{1}{4}$	$1\frac{5}{8}$	$1\frac{1}{2}$	$1\frac{1}{2}$	2	$1\frac{9}{16}$	$1\frac{5}{8}$	$1\frac{5}{8}$	$2\frac{1}{8}$	$1\frac{9}{16}$	34
35	$1\frac{3}{8}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{3}{8}$	$1\frac{1}{8}$	2	$1\frac{1}{2}$	$1\frac{3}{8}$	$1\frac{3}{8}$	$1\frac{3}{4}$	$1\frac{5}{16}$	35
36	none	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{3}{8}$	$\frac{7}{8}$	$2\frac{1}{8}$	—	$1\frac{3}{8}$	$1\frac{3}{8}$	—	$1\frac{1}{16}$	36
37	none	$1\frac{1}{4}$	none	$1\frac{1}{2}$	$1\frac{3}{8}$	$2\frac{1}{2}$	$1\frac{7}{16}$	$1\frac{1}{2}$	$1\frac{1}{2}$	—	$1\frac{3}{4}$	37
38	$13\frac{1}{2}$	$11\frac{1}{2}$	$9\frac{1}{4}$	$12\frac{1}{4}$	$12\frac{1}{2}$	19	$16\frac{1}{4}$	$17\frac{1}{2}$	$17\frac{1}{2}$	20	16	38
39	20	12	13	14	$12\frac{5}{8}$	$20\frac{1}{4}$	17	18	18	$21\frac{3}{4}$	$18\frac{1}{4}$	39
40	$13\frac{1}{2}$	$11\frac{1}{2}$	$13\frac{1}{2}$	$12\frac{1}{4}$	$12\frac{1}{4}$	19	$16\frac{1}{4}$	$17\frac{1}{2}$	17	19	$15\frac{1}{2}$	40
41	1 of 22 1 of 19	17	18	17	18	$28\frac{1}{2}$	$24\frac{1}{2}$	28	26	$28\frac{1}{2}$	2 of 21 2 of 23	41
42	1695	1560	1394	1740	3666	4466	3674	3314	3844	4762	5290 S E 7024 P E	42
43	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{5}{8}$	43

	173	243	296	465	516	572	1016	Indicated Horse-power.	
44	3 0	4 0	4 4	5 0	4 10	5 5¼	5 8	Length of condenser-tubes in feet and inches	44
45	376	390	733	780	993	1223	1820	Total condensing surface in square feet ..	45
46	10	10½	10½	7½	15	12 P 24 B	30	Diameter of circulating pump in inches ..	46
47	6	6	6¾	18	11	9	—	Length of stroke of circulating pump	47
48	R	R	R	R	R	R	C	Circulating pump, reciprocal or centrifugal..	48
49	1	1	1	1	1	1	1	Number of circulating pumps	49
50	6 3 2	8 3 2	15 16	15 15	24 . 6	29 7	64 7	Weight of boilers in tons and cwts.	50
51	3 14 0	5 6 0	15 0	11 8	15 14	19 12	21 6	Weight of water in boilers in tons and cwts.	51
52	25 6 0	45 0 0	65 13	74 0	—	128 0	167 16	Total weight of machinery and water in tons	52
53	21 12	39 13	50 13	62 4	—	—	143 9 2	Total weight of machinery exclusive of water	53
54	65	60	65	64	70	64	60	Steam pressure in boiler in lbs. per sq. inch	54
55	1	1	2	2	1	2	3	Number of boilers	55
56	5 9	7 6	7 6	15 0	13 0	9 0	15 7	Length of boilers in feet and inches	56
57	9 5	round	8 7	round	round	round	round	Height of boilers	57
58	—	7 9	—	6 6	11 2	10 4	7 10½	Diameter of boilers	58
59	7 0	—	7 0	—	—	—	—	Breadth of boilers	59
60	2 2	2 6	3 3	2 9	4 0	4 4	4 4	Diameter of funnel	60
61	19 0	24 0	22 6	28 6	36 0	38 0	40 3	Height of funnel above boilers	61

	1189	1258	1305	1319	2334	3388	3470	3666	4130	5429	7713	
44	6 10½	6 5¼	7 10	6 8	6 3	8 6	7 0	8 3	7 9	8 6	5 3 P E 7 0 S E	44
45	2560	2206	2401	2549	3746	8351	5657	6014	6554	8904	14042	45
46	15	16 P 30½ B	24	19	10	19	36	36	36	60	45	46
47	24	12⅝	—	16	33	30	—	—	—	—	—	47
48	R	R	C	R	R	R	C	C	C	C	C	48
49	1	1	1	1	2	2	2	2	2	1	2	49
50	91 6	56 16	55 1	66 16	64 7	161 16	151 16	226 16	160 7	287 12	228 5	50
51	58 0	36 0	38 16	47 0	45 0	138 16	112 0	153 0	126 6	204 0	149 2	51
52	318 0	237 0	268 10	—	302 0	879 6	678 0	876 0	745 0	1112 6	1008 18	52
53	260 8	201 8	228 14	—	256 0	740 10	556 4	717 6	619 16	902 6	803 4	53
54	76	78	66	70	51	57	60	60	60	70	65	54
55	2	2	4	2	4	8	6	12	6	8	12	55
56	24 6	16 5	8 9	16 6	9 2	9 2	16 7	10 2	16 9	19 10	4=9 5½ 8=9 6¾	56
57	12 9	round	round	14 7	10 2	round	round	14 3	round	14 4½	8 of 13 4	57
58	—	10 9	10 4	—	12 6	12 2	10 7	—	4 of 12 2 of 9 10	—	4 of 11 2	58
59	10 3	—	—	9 2½	—	—	—	8 5	—	8 9	8 of 12 4	59
60	7 0	5 8	4 0	7 0	oval 6 10 × 4 10	6 5½	6 6	9 10	7 0	oval 9 3 × 8 0	1 of 7 7 1 of 8 4	60
61	51 0	47 3	38 0	41 0	36 0	53 0	53 0	54 10	53 0	54	56	61

	173	243	296	465	516	572	1016	Indicated Horse-power.	
62	1	1	1	1	1	1	1	Number of funnels	62
63	2	2	4	4	4	4	6	Number of furnaces	63
64	4 6	4 8	4 6	4 6	4 6	5 6	5 6	Length of fire-grates	64
65	2 6	2 6	2 6	2 6	3 0	3 0	3 0	Breadth of fire-grates	65
66	22·5	23	45	45	54	66	99	Total area of fire-grates in square feet	66
67	98	110	265	203	290	344	380	Heating surface in furnaces and uptakes in sq. ft.	67
68	414	500	935	1019	1930	1892	2020	Heating surface in tubes in square feet	68
69	512	610	1200	1222	2220	2236	2400	Total heating surface	69
70	176	128	240	236	536	344	468	Number of tubes	70
71	4 0	5 6	5 5	6 0	5 0	6 6	5 6	Length of tubes in feet and inches	71
72	2¼	2¾	2¾	2¾	2¾	3¼	3	Diameter of tubes in inches..	72
73	3·85	4	8	8	16·7	16·5	20	Sectional area through tubes in square feet ..	73
74	2·96	2·51	4·05	2·62	4·30	3·90	2·36	Heating surface per indicated HP. in sq. feet ..	74
75	22·75	26·52	26·66	27	41·11	33·87	24·24	Ratio of heating to grate surface	75
76	—	—	—	—	—	462	342	Area of midship section at trial, in square feet	76
77	—	—	—	—	—	2448	1030	Displacement in tons at trial	77
78	8·60	8·91	9·69	9·58	not taken	8·68	11·6	Speed of vessel in knots per hour	78
79	100 0	—	137 0	—	274 0	239 6	170 0	Length of vessel in feet and inches	79
80	21 0	—	24 0	—	30 6	30 6	36 0	Breadth of vessel	80
81	11 6	—	—	—	25 8	25 8	16 9	Depth of vessel	81
82	200	257	383	295	937	1097	1054	Tonnage	82
83	8 10½	8 0	12 0	9 0	16 0	17 2	13 9	Mean draught of water at trial, in ft. and inches	83

COMPOUND MARINE ENGINES—*continued.*

	1189	1258	1305	1319	2334	3388	3470	3666	4130	5429	7713	
62	1	1	2	1	1	2	2	1	2	2	2	62
63	8	8	8	8	12	24	24	24	32	32	32	63
64	6 0	5 9	6 8	5 9	6 0	6 0	5 9	6 6	5 6	6 6	7 0	64
65	4 0	3 3	3 0	3 2	2 11	3 1½	3 4	3 2	3 0	3 3	3 1½	65
66	192	149	160	145	210	450	464	494	578	680	700	66
67	1030	680	655	636	1052	2100	2220	2480	2530	3600	2910	67
68	3540	3880	3655	4070	4600	8100	8400	12000	10728	15490	15870	68
69	4570	4560	4310	4706	5652	10200	11120	14480	13258	19090	18780	69
70	376	712	688	744	1248	1528	1680	1824	2020	2368	2898	70
71	9 0	6 5	6 3	6 5	5 8	6 3	6 3	7 2	6 3	7 2	6 5¼	71
72	4	3¼	3¼	3¼	2¼	3¼	3¼	3½	3¼	3½	3¼	72
73	26·5	33	32·7	32·5	34·6	72	77	—	92	127	145	73
74	3·84	3·62	3·30	3·56	2·42	3	3·20	3·95	3·21	3·51	2·43	74
75	23·80	30·60	26·93	32·45	26·96	22·66	23·98	29·31	22·95	28·36	26·82	75
76	432	—	—	—	425	—	—	—	739	—	—	76
77	—	—	—	—	1746	—	5075	—	6170	—	3290	77
78	12·5	10·75	12·72	not taken	13·08	15·28	not taken	not taken	not taken	not taken	18·57	78
79	340 0	316 0	250 0	310 0	212 0	—	395 4	437 6	413 6	475 0	300 0	79
80	35 0	35 0	31 0	34 0	36 0	—	44 0	41 0	46 3	46 0	46 1	80
81	—	26 10	—	24 0	19 4	—	38 4	32 0	32 9	—	—	81
82	1965	1948	1145	—	1268	—	3795	3692	4343	4610	3735	82
83	15 6½	20 6	9 0	—	15 0	18 6½	24 0	—	21 0	—	18 4½	83

Compound Marine Engines. (From actual Practice.)

(Bramwell, 'Trans. Inst. Mech. Engrs.,' 1872.)

	Class.	Cylinders.		Stroke.	Speed.		Diam. of Screw.	Indicated Horse-power.			Steam Pressure per square inch.			Coal Consumption.	
		Diam. High.	Diam. Low.		Revs. per Min.	Piston, Ft. per Min.		High.	Low.	Total.	Boiler.	Mean Effective. H. Cyl.	Mean Effective. L. Cyl.	24 Hours.	Indtd. H.-P.
		inches.	in.	in.			feet.				lbs.	lbs.	lbs.	tons.	lbs.
A	1	42	75	42	47	329	17	373	420	793	58	27	10·3	24·5	2·8
B	1	45	80	36	51	306	15½	476	349	825	51	34·2	7·5	23	2·6
C	1	36	72	50	50	417	14¾	467	393	860	46	36·4	7·6	24	2·6
D	1	62	112	48	47½	381	18	787	665	1452	45	22·6	5·8	33·8	2·18
E	1	38	68	33	61	335	12	298	311	609	45	25·8	8·4	13·8	2·12
F	1	34	59	36	58	348	16	304	336	640	55	35·8	10·5	14·5	2·11
G	1	51	86	48	54	431	18	723	766	1489	49	26·9	10	33·2	2·08
H	1	46	80	39	65	422	14	527	710	1237	54	24·8	11	27·6	2·08
J	1	60	104	48	60	480	18	1027	1493	2520	52	25	12·1	55·8	2·07
K	1	41	70	39	70	455	15	361	525	886	58	20·8	9·6	19·5	2·05
L	1	46	82	48	54	432	17	761	6[illegible]3	1394	54	35	9·1	30	2·01
M	1	48½	84½	42	61	427	16	669	700	1369	55	28	9·6	30	2·00
N	1	34½	60	36	53	316	15	222	226	448	54	15	8·4	9·6	2·00
O	1	36	72	50	52	433	14¾	457	401	858	54	34·2	7·5	18·0	1·95
P	1	26	52	36	51	306	17	153	211	364	53	31	10·7	7·6	1·94
Q	1	44	78	42	57	399	1[illegible]½	456	508	964	60	24·8	8·7	16·5	1·70
R	2	38	76	51	25½	216	paddle	553	432	985	55	37·3	7·3	18·0	1·70
S	3	22	52	36	55	330	14	292	204	496	48	38·6	6·5	11·2	2·12

Class 1. Compound engine with 1 high and 1 low pressure cylinder; vertical; cranks at right angles.
2. " " 2 " 2 " cylinders; inclined; " "
3. " " 2 " 2 " combined annular.

The consumption of coal is the average for long voyages.

Compound Marine Engine Boilers. (From actual Practice.) (Bramwell.)

	No. of Boilers.	Boiler Shell. Diam.	Boiler Shell. Length.	Boiler Shell. Thickness.	Furnace Flues. Total No.	Furnace Flues. Diam.	Tubes. Total No.	Tubes. Length.	Tubes. Extrnl. Diam.	Total Grate Area.	Working Pressure of Steam.	Heating Surface, in square feet. Tubes.	Heating Surface, in square feet. Furnace.	Heating Surface, in square feet. Total.	Indicated HP.	Heating Surface per Ind. HP.
		ft. in.	ft. in.	in.		ft. in.		ft. in.	in.	sq. ft.	lb. a sq. ft.					sq ft.
A	2	13 1	10 7	·87	8	2 10	456	8 0	3·50	136	60	3342	726	4068	793	5·12
B	4	10×13½	9 5	·62	12	2 10	600	7 0	3·50	187	52	3850	1158	5008	825	6·07
C	4	10×13½	9 5	·62	12	2 10	600	7 0	3·50	187	54	3850	1158	5008	860	5·82
D	8	12 0	8 0	·75	24	3 1	1392	5 6	2·75	333	50	5510	1745	7255	1452	5·00
E	1	12 0	12 0	·75	6	3 1	506	5 0	2·62	104	48	1738	289	2027	609	3·33
F	2	14 3	9 3	·87	6	3 6	420	6 3	3·75	115	60	2557	603	3160	640	4·94
G	2	13 4	18 8	·81	12	3 3	840	7 6	3·62	228	60	5959	968	6927	1487	4·65
H	2	11 9	12 6	·75	12	2 10	816	5 0	2·62	170	56	2799	623	3422	1237	2·77
J	3	12 3	16 0	·78	18	3 0	960	6 9	3·75	297	56	6355	1325	7680	2520	3·05
K	2	11 0	13 6	·75	8	3 0	568	5 6	3·25	114	60	2607	491	3098	886	3·50
L	2	12 7	17 1	·75	12	3 0	868	7 0	3·25	216	60	5164	902	6066	1394	4·35
M	2	13 3	18 0	·87	12	3 3	868	6 6	3·50	234	55	5060	1150	6210	1369	4·54
N	1	13 6	15 9	·87	6	3 2	396	6 4	3·50	107	60	2268	427	2695	448	6·02
O	2	12 3	17 6	·75	8	3 6	552	7 6	3·75	168	55	4067	575	4642	858	5·41
P	2	9 10	10 1	·62	4	2 11	268	7 3	3·25	66	50	1677	305	1982	364	5·45
Q	2	10 6	17 6	·69	8	3 3	816	6 4	3·00	182	60	4000	720	4720	964	4·90
R	2	12 0	16 6	·75	12	3 0	472	7 0	3·75	180	55	3243	761	4004	985	4·06
S	2	9×14	9 2	·56	4	3 3	324	6 6	3·50	[illegible]6	65	1790	502	2292	496	4·62

COMPOUND MARINE ENGINES—SURFACE CONDENSERS. (From actual Practice.) (Bramwell.)

	Indicated Horse-power.	Working Pressure of Steam.	Condenser Tubes.					Total Surface.	Circulating Pump.			Vacuum in Condenser.	Condensing Surface.	
			No.	Length.		External Diam.	Space between.		No.	Diameter.	Stroke.		Per Ind. HP.	Pr. sq. ft. Heating Surface.
		lb. a sq. in.		ft.	in.	in.	in.	sq. ft.		in.	in.	in. max.		
A	793	60	1797	6	0	1·00	·62	2821	1	26	21*	26	3·56	·69
B	825	52	4872	5	6	·56	·44	3944	1	36	24*	26	4·78	·79
C	860	54	2064	7	6	·75	·37	3040	1	30	25*	26	3·53	·61
D	1452	50	2415	14	1	·75	·35	6666	2	13½	32½†	28	4·59	·92
E	609	48	911	9	2	·75	·35	1654	1	13	15¾†	28½	2·72	·82
F	640	60	1342	7	2	1·00	·75	2573	centrifugal			28	4·02	·81
G	1489	60	1759	8	6	1·00	·75	3914	centrifugal			26½	2·63	·57
H	1237	56	1289	10	10	·75	·35	2752	1	16	20½†	27½	2·22	·80
J	2520	56	2257	14	1	·75	·35	6249	2	13	26½†	27¾	2·48	·81
K	886	60	898	12	5	·75	·35	2189	1	14	17½*	27	2·47	·71
L	1394	60	2304	6	9	1·00	·62	4078	1	26	25½*	25	2·92	·67
M	1369	55	1725	13	4	·75	·37	4504	1	19½	16†	28	3·29	·73
N	448	60	890	7	9	1·00	·75	1811	1	21	36*	27	4·04	·67
O	858	55	2064	7	6	·75	·37	3040	1	30	25*	27	3·54	·65
P	364	50	944	6	0	·75	·31	1112	1	20½	19½*	27	3·04	·56
Q	964	60	1338	12	7	·75	·37	3250	1	18½	15†	29	3·37	·69
R	985	55	1663	8	3	·75	·35	2694	2	16	20†	27½	2·74	·67
S	496	65	608	7	10	1·00	·87	1246	1	22	18*	26½	2·51	·54

* Single acting. † Double acting.

Animal Power.

Working 8 hours per day.	In lbs. raised 1 ft. per min.	Working 8 hours per day.	In lbs. raised 1 ft. per min.
Horse	21,000	Man, as in rowing ..	4000
Ox..	12,000	Ditto on tread-wheel	3100
Mule	10,000	Turning a handle ..	2600
Ass	3,500		

WATER-POWER.

Theoretical Horse-power of Water.

Q = Quantity of water in cube feet per minute.
h = Head of water from tail-race in feet.
P = Theoretical horse-power.

$P = {\cdot}001892\, Q\, h.$ $\qquad$ $Q = \dfrac{528{\cdot}5\, P}{h}.$

Effective Horse-power for Different Motors.

Theoretical power being	= 1·00
Undershot water-wheels	= ·35
Poncelet's undershot water-wheel	= ·60
Breast-wheel	= ·55
High-breast	= ·60
Overshot wheel	= ·68
Turbine	= ·70
Hydraulic ram raising water ..	·60
Water-pressure engine	80

Undershot Water-wheel.

Velocity of periphery of the undershot water-wheel should equal the theoretical velocity due to the head of water × 0·57.

Or = ·57 V. For values of V, see Table of theoretical velocity of water.

h = Head of water in feet.
Q = Quantity of water in cube feet per minute.
P = Effective horse-power.

$Q = \dfrac{1511\, P}{h}.$ $\qquad$ $P = {\cdot}00066\, Q\, h.$

Poncelet's Undershot Water-wheel.

h = Head of water in feet.
Q = Quantity of water in cube feet per minute.
HP = Effective horse-power.

$$Q = \frac{880 \text{ HP}}{h}. \qquad \text{HP} = \cdot 00113\, Qh.$$

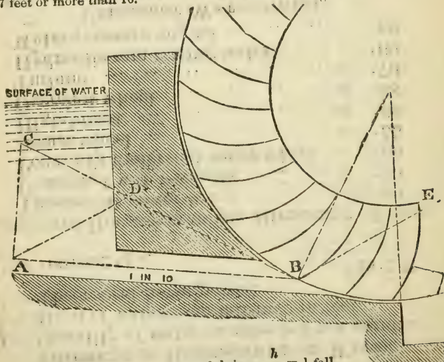
Velocity of periphery $= V \times 0 \cdot 55$.

For values of V, see Table of theoretical velocity of water.

Number of buckets $= 1 \cdot 6\, D + 16$ when D = diameter of wheel in feet.

The sluice-opening should be covered by at least two buckets.

Depth of shrouding from $\frac{1}{3}$rd to $\frac{1}{2}$ of the fall of water. Diameter of wheel $= 2h$; but the diameter of the wheel should not be less than 7 feet or more than 16.



Greatest depth of opening of sluice $= \frac{h}{8} = \frac{1}{8}$ fall.

Construction of floats:—

Let A B represent the direction of the supply, and lay off a tangent to the periphery of the wheel at the centre of the sluice. Raise A C perpendicular to A B, and make C D = ·4 B C. Join A D and draw B E parallel to A D; then B E is the tangent to the curve of the float at its point. The curve may be struck with a radius of 1·2 depth of shrouding.

The curb should fit the wheel accurately for 18 or 20 inches, measured back from the perpendicular line which passes through the axis of the wheel; the breast should then incline 1 in 10, or 1 in 15 towards the sluice.

After passing the axis of the wheel in the tail-race the curb should make a sudden dip of 6 inches.

Floating Mill-wheels.

Velocity of periphery of wheel = Velocity of stream × ·4.

Diameter of wheels generally from 12 to 15 feet.

Number of floats generally from 9 to 11.

Inclination of floats from radial line about 25° to 30°.

Depth of floats from 24 to 30 inches.

Dip of floats from 12 to 15 inches.

Not less than two floats should be immersed at once.

Effective Power of Floating Mills.

V = Velocity of stream in feet per second.

v = Mean velocity of float in feet per second.

A = Immersed area of floats in square feet.

P = Horse-power. $P = \cdot 0028\, V v A (V - v)$.

Note.—These wheels seem never to be made with curved floats. Floats, if made of a somewhat similar form to those of Poncelet's undershot wheel, would probably give a greater effect.

Breast and Overshot Wheels.

h = Head of water in feet.

Q = Quantity of water in cube feet per minute.

P = Effective horse-power.

$Q = \dfrac{961\, P}{h}$ in low-breast wheels.

$Q = \dfrac{381\, P}{h}$ in high-breast wheels.

$Q = \dfrac{777\, P}{h}$ in overshot wheels.

$P = \cdot 00104\, Q h$ in low-breast wheels.

$P = \cdot 00113\, Q h$ in high-breast wheels.

$P = \cdot 00128\, Q h$ in overshot wheels.

Breast and Overshot Wheels—*continued.*

VELOCITY OF PERIPHERY.

V = Velocity of periphery in feet per second.
h = Fall of water in feet.

When h = 5 feet	**V** = 7 feet per second.
= 10	= 6·6
= 15	= 6·2
= 20	= 5·8
= 25	= 5·4
= 30	= 5·0
= 35	= 4·6
= 40	= 4·2
= 45	= 3·8
= 50	= 3·4

DISTANCES OF BUCKETS APART.

12 inches in high-breast or overshot.
18 inches in low-breast.

OPENINGS OF BUCKETS.

$\frac{1}{3}$ of a square foot to each cube foot of contents of bucket in high-breast.

$\frac{1}{5}$ of a square foot to each cube foot of contents of bucket in low-breast.

Or generally about 6 to 8 inches width of opening in high-breast. And about 9 to 12 inches width of opening in low-breast.

Depth of shrouding from 12 in. in high-breast.
" " " 16 in. in low-breast.

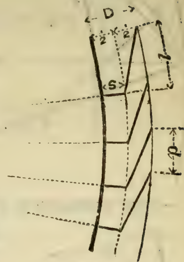
APPROXIMATE RULE SOMETIMES USED FOR THE NUMBER OF BUCKETS.

D = Diameter of wheel in feet.
N = Number of buckets.

For wheels from 12 to 25 ft. diam.,	**N** = **D** × 2·1
" " 25 " 40 "	**N** = **D** × 2·3
" " 40 " 50 "	**N** = **D** × 2·4

Breast and Overshot Wheels—*continued.*

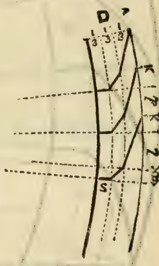
FORMS OF BUCKETS.



D = Depth of shrouding.
d = Distance of buckets apart on periphery.
l = Length of wrist measured on periphery.
S = Length of start (radial).

Two-part Buckets.

D = d. S = $\frac{1}{2}$ D.
l = $1\frac{1}{4}$ D in large wheels.
l = D in wheels under 25 feet diameter.



Three-part Buckets.

Divide D into 3 equal parts.
a = Length of arm measured on periphery
D = d. S = $\frac{1}{3}$ D. $a = \frac{1}{4}$ D.
l = D in large wheels.
$l = \frac{3}{4}$ D in wheels under 25 feet diameter.

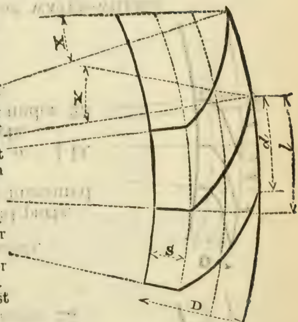
GUDGEONS OF WATER-WHEELS.

W = Weight on the gudgeon in cwts.
D = Diameter of gudgeon-journal in inches.
$D = \sqrt[3]{\cdot 86\ W}$ for wrought iron.
$D = \sqrt[3]{W}$ for cast iron.

BREAST AND OVERSHOT WHEELS—*continued.*

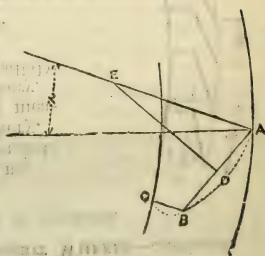
FORMS OF BUCKETS (CURVED).

D = Depth of shrouding.
d = Distance of buckets apart at periphery.
S = Length of start (radial).
X = Angle of radius of bucket curve, with radial line of wheel at points of bucket.
l = Length of bucket curve, measured on periphery of wheel.
$D = d$. $S = \frac{1}{3} D$.
$l = 1\frac{1}{4} D$ in large wheels.
$l = D$ in wheels under 25 feet diameter.
$X = 15°$ in overshot or high-breast wheels.
$X = 25°$ in low-breast wheels.



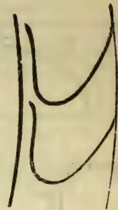
The radius of the bucket curves may be determined thus:—

From the point of the bucket A set off the line E A at the angle X, with the radius of the wheel. Draw the start C B = ⅓ depth of shrouding. Join A B and bisect the line A B at D, and raise the perpendicular D E. The points of intersection of D E with A E will be the centre from which the bucket curve will be struck with the radius A E. In practice the start is rounded, as shown by the dotted line between B C.



OVERSHOT AND BREAST WHEELS.

FAIRBAIRN'S VENTILATING BUCKETS.



The spaces for ventilation are about 1 inch wide.

TURBINES.

JONVAL'S LOW-PRESSURE,

For falls of 30 feet and under.

h = Head of water in feet.
Q = Quantity of water in cube feet per second.
P = Horse-power (actual).
A = Area of sum of orifices of buckets in feet.
D = Diam. of centre of motion of buckets in ft.
V = Velocity of buckets at centre of motion in feet per second.
d = Depth of guides.
d' = Depth of buckets.

$$D = 1{\cdot}33 \sqrt{\frac{Q}{\sqrt{h}}}.$$

$$Q = 12{\cdot}67 \frac{P}{h}. \qquad P = {\cdot}079\, Q\, h.$$

$$V = 6 \sqrt{h}$$

$$*A = \frac{Q}{V}.$$

$d = D \times {\cdot}26.$
$d' = D \times {\cdot}18.$

No. of buckets $= 17 \sqrt{D}.$
No. of guides = No. of buckets $\times {\cdot}7.$

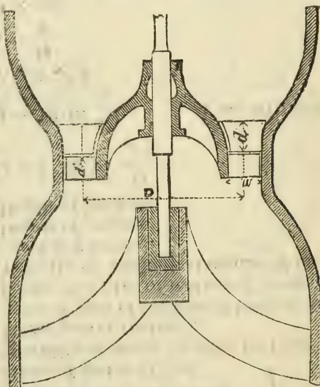
* The orifices are the distances $a^1\, b$, $a^2\, b^1$, &c., &c. × width of the buckets w. See diagrams, next page.

JONVAL'S TURBINES—*continued.*

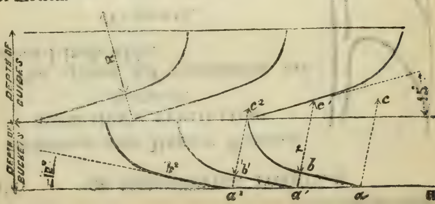
DIAGRAMS ILLUSTRATIVE OF JONVAL'S TURBINE.

Vertical Section of Turbine.

D = Diameter of centre of motion in buckets.
w = Width of buckets.
d = Depth of guides. d' = Depth of buckets.



Development of buckets and guides on the line of the centre of motion.



JONVAL'S TURBINES—*continued.*

CONSTRUCTION OF BUCKETS.

On the line B B set off the distances of the buckets apart a, a^1, a^2, and from the points a, a^1, a^2, draw the lines $a\,b$, $a^1\,b^1$, $a^2\,b^2$, at an angle of 12° with the line B B; from the points a, a^1, a^2, set off lines $a\,c$, $a^1\,c^1$, &c., at right angles to the line $a\,b$, $a^1\,b^1$; the lines $a\,c$, $a\,c$, determine the lengths of the *straight* portion of the buckets; then on the lines $a\,c^1$, $a^1\,c^2$, from the point $b\,b^1$, lay off distance $b\,c^1$, $b^1\,c^2$ = depth of the buckets; then the point $c^1\,c^2$ are the centres from which the curved portions of the buckets are described, with a radius = depth of buckets.

The guides are constructed in the same manner, but with a different radius and angle, as below.

BUCKETS.

Radius of curved portion of bucket = Depth of bucket D.

*Angle of straight portion of bucket = 12° with horizontal line.

Length of straight portion of bucket = Distance of buckets apart on the horizontal line.

GUIDES.

Radius of curved portion of guides = Depth of guides.

*Angle of straight portion of guides = 15° with horizontal line.

Length of straight portion of guides = Distance of guides apart on the horizontal line.

When the buckets and guides are made entirely straight—

Angle of bucket = 24° with horizontal line.
Angle of guides = 66° ,,

* When the quantity of water is large these angles may be increased.

TABLE OF LOW-PRESSURE TURBINES.

(From actual Practice.)

h = Head of water in feet.
V = Velocity of centre of buckets in ft. per sec.
Q = Quantity of water in cube feet per second.
R = Revolutions of turbine per minute.
HP = Effective horse-power.

h.	V.	5 HP.		10 HP.		15 HP.		20 HP.		30 HP.	
		Q.	R.	Q.	R.	Q.	R.	Q.	R.	Q.	R.
2½	9·48	25	34	50	24	75	20	100	17	—	—
5	13·41	12·5	81	25	57	38	47	50	41	75	33
7½	16·43	8·5	136	17	97	25	79	33	68	51	56
10	18·97	6·3	180	12·6	128	19	105	25	90	38	75
15	23·23	4·2	319	8·4	226	12·6	185	17	160	25	131
20	26·83	—	—	6·3	329	9·3	273	12·6	232	18·9	194
25	30·00	—	—	—	—	7·5	358	10	310	15·0	253
30	32·86	—	—	—	—	—	—	8·4	380	12·6	310

h.	V.	40 HP.		50 HP.		60 HP.		70 HP.		80 HP.	
		Q.	R.	Q.	R.	Q.	R.	Q.	R.	Q.	R.
5	13·41	100	28	126	26	—	—	—	—	—	—
7½	16·43	68	48	85	43	102	40	120	36	136	34
10	18·97	50	64	63	58	76	53	88	48	101	48
15	23·23	33	113	42	100	51	92	60	85	67	80
20	26·83	25	164	31	148	37	136	43	123	51	116
25	30·0	20	220	25	196	30	179	35	166	40	155
30	32·86	17	268	21	240	25	219	30	227	34	190

DIAMETER OF UPRIGHT SHAFT.

P = Horse-power, effective.
d = Diameter of shaft in inches.
R = Number of revolutions per minute.

$$d = \sqrt[3]{\frac{90\,P}{R}}.$$

HIGH-PRESSURE TURBINES—FOURNEYRON'S.

h = Head of water in feet.
Q = Quantity of water in cube feet per second.
P = Horse-power.
D = Internal diameter of turbine in feet.
E = External " "
V = Velocity of turbine at periphery in feet per second.
N = Number of buckets.
n = Number of guides.
d = Depth of orifices in feet.
A = Area of sum of orifices in square feet.

$$V = 6 \cdot 6 \sqrt{h}.$$

$$*D = \sqrt{\frac{1 \cdot 77\, Q}{\sqrt{h}}}. \qquad Q = 12 \cdot 67 \frac{P}{h}.$$

$$P = \cdot 079\, Q\, h. \qquad A = \frac{Q}{V}.$$

E = 1·2 D when D is more than 6 feet.
E = 1·4 D when D is less than 6 feet.

$$†N = 24 \sqrt{D}.$$

n = N, when N is less than 24.

$n = \frac{N}{3}$, when N exceeds 24.

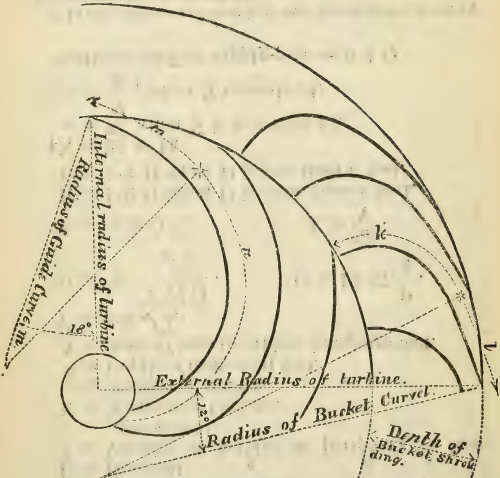
Sectional area of supply-pipe = 0·4 Q.

* In extreme cases of very high falls the diameter given by this formula may be increased.

† Fourneyron's rule for the number of buckets is the constant number 36, irrespective of the size of the turbine.

FOURNEYRON'S TURBINE.

CONSTRUCTION OF BUCKETS AND GUIDES.



BUCKETS.

Radius of curve l .. .. = External radius of turbine.

Length of curve l .. .. = Distance of buckets apart on periphery.

Angle of radius of curve l = 12° with external radius of turbine.

Radius of curve k .. .. = $\frac{3}{4}$ depth of bucket shrouding.

Fourneyron's Turbines—*continued.*

Guides.

Radius of curve m	= Internal radius of turbine.
Length of curve m	= Distance of guides apart on their periphery.
Angle of radius of curve m	= 18° with internal radius of turbine.
Radius of curve n	= $\frac{1}{2}$ internal radius of turbine.

High-pressure Turbines.

h = Head of water in feet.
Q = Quantity of water required for each 10 horse-power.
V = Velocity of turbine at periphery in feet per second.

h =	30	40	50	60	70	80	90	100	120	140	160	180	200
Q =	4·2	3·1	2·5	2·1	1·8	1·6	1·4	1·27	1·05	0·9	·8	·7	·63
V =	36	42	47	51	55	59	63	66	73	78	84	89	94

Hydraulic Ram.

Q = Quantity of water used in cube feet per minute.
h = Head of water in feet.
P = Effective horse-power.

$$Q = \frac{881\ P}{h}. \qquad P = \cdot 00113\, Q\, h.$$

The length of the supply-pipe should not be less than $\frac{3}{4}$ths of the height to which the water is to be raised.

Diameter of supply-pipe = $1 \cdot 45 \sqrt{Q}$.

Ditto of rising pipe .. = $\cdot 75 \sqrt{Q}$.

Contents of air-vessel = contents of rising pipe.

$\frac{1}{7}$th of the water may be raised to about 4 times the head of supply, or $\frac{1}{14}$th eight times, or $\frac{1}{28}$th sixteen times, &c.

WATER-PRESSURE ENGINES.

For Pressure per square inch at different Heads, see Tables of pressure of water.

POWER OF PRESSURE ENGINES.

Q = Quantity of water in cube ft. per minute.
h = Head of water in feet.
P = Effective horse-power.

$$Q = \frac{661\ P}{h}.$$

$$P = \cdot 00151\ Q\ h.$$

Wrought-iron pipes are frequently used for high-pressure turbines.

D = Internal diameter of pipe in inches.
P = Pressure of water in atmospheres.

$$\text{Thickness of metal in inches} = \frac{D\ P}{800} + 0 \cdot 2.$$

33 feet from the top = 1 atmosphere nearly.

Thickness of metal in cylinder = $P\ d \cdot 0025 + 1$ where d = diameter of cylinder, in inches.

Diameter of supply-pipe for water-pressure engines = diameter of cylinder × ·41 for single-cylinder engines.
= diameter of cylinder × ·68 for double-cylinder engines.

Stroke of engine, about $4\frac{1}{2}$ diam. of cylinder.

Velocity of piston, 60 feet per minute.

Velocity of water in supply-pipe should not exceed 400 feet per minute

Hydraulic Press.

D = External diameter of press in inches.
d = Internal " " "
P = Working pressure of press, tons per square inch.
S = Safe working stress on metal, tons per square inch.

$$\text{Hyp. log. } \frac{D}{d} = \frac{P}{S}. \qquad D = d\,x.$$

Values of x.

If $\frac{P}{S}$ =	·2	·3	·4	·5	·6	·7	·8
x =	1·23	1·35	1·49	1·65	1·82	2·01	2·23
If $\frac{P}{S}$ =	·9	1·0	1·1	1·2	1·3	1·4	1·5
x =	2·46	2·72	3·01	3·32	3·67	4·06	4·48

Assuming safe working stress of cast iron = 1¼ tons per square inch, the following are the values of x:—

	Working Pressure, Tons per Square Inch.									
P =	·5	·6	·7	·8	·9	1·0	1·25	1·50	1·75	2·00
x =	1·4	1·49	1·6	1·71	1·82	1·95	2·3	2·72	3·21	3·79

Hydraulic Machinery.

Tweddell in his hydraulic riveting machines uses pressures varying from 1000 to 1750 lbs. per square inch (say from ·45 to ·78 ton per square inch).

The accumulator is supplied by two pumps, 3-inch stroke, each 1⅜ diameter, making from 100 to 120 revolutions per minute. Armstrong uses for crane work a pressure of 700 lbs. per square inch (say ·3125 ton).

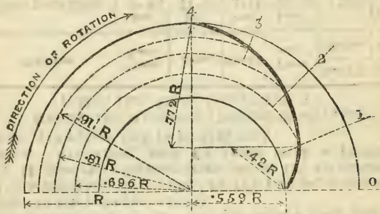
Hydraulic Machines (Toulon Dockyard).
('Min. Inst. Mech. Engrs.,' 1878.)

Machine.	Diam. Ram.	Area.	Stroke	Pressure.	Daily Work 10 hrs	
					Strokes.	Water.
	ins.	ins.	ins.	tons.		cub. ft.
Plate punching	9·93	77·5	3·15	49·21	1200	188
Ditto "	14·05	155	3·94	98·42	600	235
∟ iron shearing	12·17	116·25	6·69	73·81	400	200
Ditto "	17·21	232·5	9·45	147·63	200	282
Plate flanging	15·39	186	13·78	118·10	50	82
Channel iron bending ..	9·93	77·5	11·81	49·21	200	118
	14·05	155	11·81	98·42	100	118

CENTRIFUGAL PUMPS.

(D. Thomson, 'Trans. Inst. Civ. Eng.,' vol. xxxii.)

DIAGRAM OF FORM OF VANES.



Divide the quarter circumference into four equal parts with radial lines; then draw concentric circles with radii = ·559 R, ·696 R, ·81 R, and ·91 R respectively; then the intersection of these circles with the radial lines gives points in the curve of the vane.

The number of vanes is generally 6.

Duty of vanes of this form = ·68; if radial vanes = ·46.

An 18-inch pump will work well with 20 ft. lift.
36-inch " " " 30 ft. "

D = Diameter of fan in feet.
H = Head of water in feet, including head corresponding with friction of pipes, &c.
S = Speed of periphery of fan, feet per second.
Q = Quantity of water lifted, feet per minute.

$S = 8\sqrt{H}$ in small fans; $= 9 \cdot 5\sqrt{H}$ in large fans.

$H = \frac{S^2}{64}$ " " ; $= \frac{S^2}{90 \cdot 25}$ " "

$D = c\sqrt{\frac{Q}{\sqrt{H}}}$; the value of c varying from ·12 to ·18 (Unwin).

Diam. of fan, inches	12	15	18	21	24	30	36
Discharge, gals. per min.	1200	1800	2700	3600	4800	7500	10800

To find the Force of the Wind.

V = Velocity of wind in feet per second.
v = Velocity in miles per hour.
P = Pressure in lbs. per square foot.
*x = Angle of incidence of direction of the wind with the plane of the surface when it is oblique.

$P = 0{\cdot}002288\ V^2.$
$P = {\cdot}00492\ v^2.$
$P = {\cdot}0023\ V^2 \times \sin. x.$

Miles per hour.	Feet per minute.	Feet per second.	Force in lbs. per sq. foot.	Description.
1	88	1·47	·005	Hardly perceptible.
2	176	2·93	·020	Just perceptible.
3	264	4·4	·044	
4	352	5·87	·079	Gentle breeze.
5	440	7·33	0·123	
10	880	14·67	0·492	Pleasant breeze.
15	1320	22	1·107	
20	1760	29·3	1·968	Brisk gale.
25	2200	36·6	3·075	
30	2640	44	4·428	High wind.
35	3080	51·3	6·027	
40	3520	58·6	7·872	Very high wind.
45	3960	66·0	9·963	
50	4400	73·3	12·300	Storm.
60	5280	88·0	17·712	Great storm.
70	6160	102·7	24·108	
80	7040	117·3	31·488	Hurricane.
100	8800	146·6	49·200	

Cyclones.

Direction in the Northern Hemisphere.

Direction in the Southern Hemisphere.

Rule for finding the Centre of a Cyclone.—Face the wind; and about 10 points (112½°) to the right will be the direction of the centre in the Northern Hemisphere or to the left in the Southern Hemisphere.

WINDMILLS.

RULE FOR THE ANGLES OF THE SAILS.

A = Angle of the sail with the plane of motion at any part of the sail.
R = Total radius of sail in feet.
D = Distance of any part of the sail from the axis.

$$A = 23^\circ - \frac{18\,D^2}{R^2}.$$

If the radius of the windmill sails be divided into six equal parts, the angles at each of those parts will be as follows, reckoning from the axis:

Distances from axis	$\frac{1}{6}$	$\frac{2}{6}$	$\frac{3}{6}$	$\frac{4}{6}$	$\frac{5}{6}$	tip.
Angle of sail with axis ..	$67\frac{1}{2}^\circ$	69°	$71\frac{1}{2}^\circ$	75°	$79\frac{1}{2}^\circ$	85°
Angle of sail with plane of motion	$22\frac{1}{2}$	21	$18\frac{1}{2}$	15	$10\frac{1}{2}$	5

Axis of shaft of windmill with horizon
= 8° on level ground.
= 15° on high exposed positions.

Breadth of whip at axis = $\frac{1}{30}$th length of whip.
Depth " " = $\frac{1}{40}$th "
Breadth of whip at tip = $\frac{1}{60}$th "
Depth " " = $\frac{1}{80}$th "
Width of sail " = $\frac{1}{3}$rd "
divided by the whip in the proportion of 5 to 3, the narrow portion being nearest to the wind.

Width of sail at axis .. = $\frac{1}{5}$th length of whip.
Distance of sail from axis = $\frac{1}{7}$th "
Cross-bars from 16 to 18 inches apart.

ORDINARY DIMENSIONS OF WINDMILL SAILS.

Length of whip	30 feet.
Breadth of base	12 inches.
Depth at base	9 „
Breadth at tip	6 „
Depth „	$4\frac{1}{2}$ „

HORSE-POWER AND SAIL-AREA OF WINDMILLS.

HP = Horse-power.
V = Velocity of wind in feet per second.
A = Total area of sails in square feet.
N = Number of sails.

$$A = \frac{HP\ 1080000}{V^3}.$$

$$HP = \frac{A\,V^3}{1080000}.$$

Area of each sail $= \frac{A}{N}$.

Velocity of tips of sails = 2·6 V, nearly.

COEFFICIENTS FOR EFFLUX OF AIR FROM ORIFICES.

Vena contracta	·98
Conical converging	·9
Cylindrical rounded at ends ..	·9
Cylindrical throughout	·8
Thin plates	·6

CENTRIFUGAL FANS.

D = Diameter of fan.
V = Velocity of tips of fan in feet per second.
P = Pressure in lbs. per square inch.

$$V = \sqrt{P \times 97300}.$$

$$P = \frac{V^2}{97300}.$$

POWER REQUIRED FOR FANS.

p = Pressure of blast in lbs. per square inch.
A = Area of the sum of the tuyeres in square inches.
V = Velocity of tips of fan in feet per second.
HP = Indicated horse-power required.
HP = $\cdot 000016\ V^2\ A\ p$.

PROPORTIONS OF FANS.

Length of vanes $= \frac{D}{4}$. Width of vanes $= \frac{D}{4}$.

Diameter of inlet $= \frac{D}{2}$. Eccentricity of fan $= \frac{D}{10}$.

Length of spindle journal = 4 diameters of spindle. Diameter of smith's forge nozzle, $1\frac{5}{8}$.

Smithy blast from 0·25 to 0·3 lb. per square inch. Cupola blast about 0·8 lb. per square inch.

BLOWING ENGINES.

Capacity of air-vessel = 20 times the capacity of the blowing cylinder if the cylinder is single-acting, or 10 times if double-acting.

Velocity of air in the passages should not exceed 35 feet per second. Density of blast for iron furnaces from $2\frac{1}{2}$ to 3 lbs. per square inch.

Each smith's forge requires 150 cube feet of air per minute. Density of smith's forge blast $\frac{1}{4}$ lb. per square inch. Each ton per hour melted in cupola requires 3500 cube feet per minute. Each finery forge requires 100,000 cube feet air for each ton refined. Each blast furnace 20 cube feet per minute for each cube yard capacity of furnace.

Experiments on Steam Jets.
(Siemens, 'Trans. Inst. Mech. Engrs.,' 1872.)

Compression of air into a closed vessel 225 cube feet capacity. Pressure of steam in steam boiler, 50 lbs. per square inch. Pressure of air in inches of mercury.

Area of Circular Orifice.	Time of Action of Jet in Minutes.											
	$\frac{1}{3}$	$\frac{2}{3}$	1	$1\frac{1}{3}$	$1\frac{2}{3}$	2	3	4	5	6	7	8
·07*	6	10	12	13	$13\frac{1}{2}$	14	15	$15\frac{1}{2}$	15	$14\frac{3}{4}$	$14\frac{3}{4}$	$14\frac{3}{4}$
·12*	5	9	12	16	19	$21\frac{1}{2}$	24	25	$24\frac{1}{4}$	$24\frac{1}{4}$	$23\frac{3}{4}$	$23\frac{1}{2}$
·07†	9	11	14	15	$15\frac{1}{2}$	16	$16\frac{3}{4}$	$16\frac{3}{4}$	12	11	$10\frac{1}{4}$	10

* With condensing water. † Without condensing water.

Final temperature of air in vessel: 1st experiment, 113° Ft. 2nd, 158° Ft.

Exhaustion from closed vessel, 225 cube feet capacity. Pressure in steam boiler, 45 lbs. per square inch. Vacuum in inches of mercury.

Area of Circular Orifice. Sq. Ins.	Time of Action of Jet in Minutes.						
	1	2	3	4	5	6	7
·05	9	13	$14\frac{1}{2}$	$15\frac{1}{2}$	$15\frac{3}{4}$	—	—
·10	10	$13\frac{1}{2}$	15	$15\frac{1}{2}$	$15\frac{7}{8}$	—	—
·15	$9\frac{1}{4}$	$13\frac{1}{2}$	$16\frac{1}{4}$	$17\frac{1}{4}$	18	$18\frac{1}{2}$	$18\frac{3}{4}$
·20	$8\frac{1}{2}$	13	$15\frac{3}{4}$	17	$17\frac{3}{4}$	$18\frac{1}{4}$	$18\frac{1}{2}$

1. The quantity of air delivered by a steam jet depends on the extent of surface contact between air and steam up to the limits of exhaustion and compression the jet is capable of producing.

2. The maximum degree of vacuum or pressure attainable increases in direct proportion to the steam pressure employed.

3. The quantity of air delivered per minute within effective limits is in inverse proportion to the weight of the air acted upon. Better result is obtained in exhausting than in compressing.

4. The limits of air pressure attainable with a given pressure of steam are the same in compressing and exhausting within the limit of a perfect vacuum in the latter case.

PNEUMATIC TRANSMISSION ('Min. Inst. Civ. Eng.,' vol. xliii.)

Leaden tubes are generally used.
The 3 diameters used are 3, 2¼, 1½.
The relative traffic power of the tubes was as follows:—

	Time required for Traffic.	Power required.
3″	100	100
2¼	116	49
1½	141	18

The lowest possible diameter for the traffic should be adopted.

Tubes are made in lengths of 29 feet, smoothed inside by a steel mandrel, lubricated with soft soap, and drawn through to make the bore fair and uniform.

Minimum radius of curves of the pipe, 12 feet.

The carrier is a cylindrical box of gutta-percha covered with felt; the felt projecting slightly in the rear of the carrier. The open end of the carrier is closed by an elastic band, to prevent the messages from escaping.

Tubes should be worked on the block system if worked by pressure; but, if worked by a vacuum, where there is no intermediate station, carriers may follow at short intervals.

Signalling is done by electric telegraph.

Obstructions are removed by forcing water into the pipe when they cannot be removed by air.

The distance of a fault is ascertained by firing a pistol into the tube, and calculating the distance from the time the concussion of air travels to, and is reflected back by, the obstacle; the rate for calculation being 1030 feet per second.

Engines compound; high-pressure cylinder 17 in. diam. 49½ stroke; low-pressure cylinder 25½ in. diam. 66 stroke.

Boiler, pressure 70 lbs. per square inch.

Each engine indicated 73½ horse-power at 25 revolutions per minute.

The compressing pump indicated	35½	HP.
And vacuum " "	26¾	"
Total	62¼	"

Efficiency = ·872. Compression of air = 10 lbs. above atmosphere; vacuum = 8·8 lbs. below atmosphere.

Pneumatic Transmission—*continued.*

Formula for the Velocity.

S = Velocity of carrier in tube, feet per second.
l = Length of tube in feet.
d = Diameter of tube in feet.
P = Pressure in tube in lbs. per square inch.
k = Coefficient of work.
t = Time in seconds required for a carrier to go through the tube.

$$S = k\sqrt{\frac{d}{l}}. \qquad t = \cdot 000482 \frac{1}{\sqrt{P}} \sqrt{\frac{l^3}{d}}.$$

1. lbs. per square inch.	Values of k with different pressures.				Horse-power required for each cubic foot of air per minute.	
	Pressure working		Vacuum working			
	Con-tinuous.	Inter-mittent.	Con-tinuous.	Inter-mittent.	Pressure.	Vacuum.
3	3520	3570	3770	3690	·014	·012
4	4000	4080	4420	4310	·019	·016
5	4420	4550	5030	4850	·024	·018
6	4810	4980	5620	5380	·029	·022
7	5150	5350	6170	5850	·035	·021
8	5460	5680	6760	6370	·040	·025
9	5750	6020	7350	6850	·046	·026
10	6020	6330	8000	7350	·052	·028
11	6250	6580	8700	7870	·058	·028
12	6490	6850	9430	8400	·064	·026

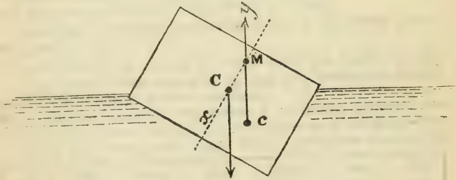
50 per cent. additional engine power should be provided in excess of the power necessary to compress or rarefy the air. 10 lbs. per square inch and pipes of 2½ inches diameter are most convenient for general purposes.

To maintain equal velocities in different lengths of tubing of the same diameter, the pressure must be varied so that $\sqrt{l} : \sqrt{l_1} :: k : k_1$.

To maintain equal velocities in tubes of the same length but different diameters; $\sqrt{d} : \sqrt{d_1} :: k : k_1$.

To maintain equal velocities when both lengths and diameters are different; $\sqrt{\frac{l}{d}} : \sqrt{\frac{l_1}{d_1}} :: k : k_1$.

Stability of Floating Bodies.



x the vertical line that passes through the centre of gravity C of the floating body when in equilibrium.

y the vertical line that passes through the centre of gravity c of the displaced fluid.

When the vessel is in equilibrium x and y coincide; but when the body is careened over the point of intersection of the two lines, x and y gives M, the position of the "metacentre." If M be above C, the equilibrium is stable; if it coincide with C, it is indifferent; if below C, it is unstable.

I = Moment of inertia of plane of flotation about an axis passing through its centre of gravity.

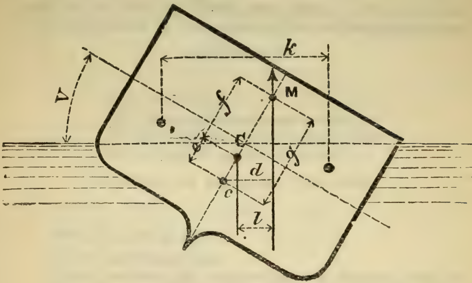
h = Height of centre of gravity of body above centre of gravity of displaced water.

V = Submerged volume.

H = Height of metacentre above centre of gravity of displaced water.

$H = \frac{I}{V}$, and $H - h$ = measure of stability.

Stability of Floating Bodies—*continued.*



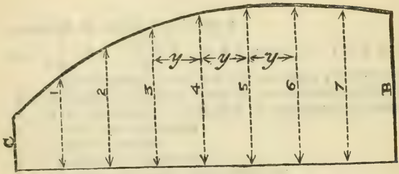
W = Weight of floating body.
d = Horizontal distance of centre of gravity of displacement c from metacentral line.
l = Horizontal distance of centre of gravity of floating body C from metacentral line.
f = Distance of C from metacentre M.
g = Distance of c from metacentre M.
e = Distance of C from c.
V = Angle of careen.
A = Area of displacement.
a = Area immersed or emerged by careening at angle V.*
k = Horizontal distance apart of the centres of gravity of the sections immersed and emerged by careening.

$$d = \frac{a\,k}{A};\quad g = \frac{d}{\text{sin. V}};\quad l = d \pm e \text{ sin. V};\quad f = g \pm e;$$

Stability of vessel = W f sin. V.

* Supposing the two sections are equal.

Simpson's Method of Calculating Areas (for displacement).



Divide the base into any number of equal parts, taking care that the number of ordinates are odd, *viz.* 7, 9, or 11, &c.

Let y = Distance of the ordinates apart.
S = The sum of the lengths of the even ordinates, 2, 4, 6, &c.
Σ = The sum of the lengths of the odd ordinates, 1, 3, 5, 7, &c.
E = The sum of the lengths of the end ordinates C and B.
A = Area of the figure.

$$A = \frac{y}{3}(E + 2S + 4\Sigma).$$

Thickness of Plates in Iron Ships.

T = Thickness of plate in inches.
S = Span unsupported by ribs in feet.
D = Depth of submergence in feet.

$$T = \cdot 05\, S \sqrt{D}.$$

Salinometer.

The temperature of water drawn from marine boilers when boiled in the open air should not exceed $215\frac{1}{2}°$ Fahr., or $1\cdot 09$ specific gravity, or $\frac{3}{32}$ degrees of saltness, as deposit commences a little beyond that point.

Propulsion of Vessels.

A = Immersed cross-section of vessel in square feet.
D = Displacement in tons.
V = Speed of vessel in knots per hour.
S = Wetted skin in square feet.
H = Indicated horse-power.
$K, x, y, \& z$ = Coefficients.
K = From ·003 to ·006; average ·005.
x = From ·0013 in vessels of large tonnage to ·0032 in small.
y = From ·000036 to ·000075; average ·000053.
z = From ·0034 in vessels of large tonnage to ·01 in small.

Formulæ.

For cross-section and skin resistance combined ..	$H = \cdot 00877 V^3 (\cdot 05\ A + K\ S)$
For sectional area alone ..	$H = V^3\ A\ x.$
For skin resistance alone ..	$H = V^3\ S\ y.$
For displacement alone ..	$H = V^3\ D^{\frac{2}{3}}\ z.$

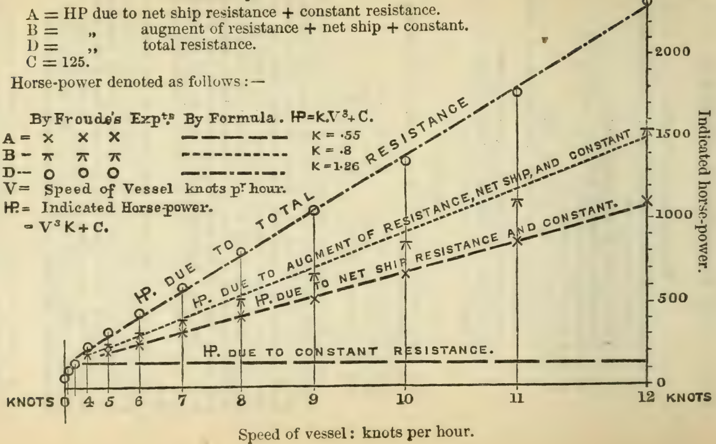
Any of these formulæ are used separately to give the total indicated horse-power; but none of them are altogether satisfactory. Mr. Froude in a paper read at the Institution of Naval Architects, April 7th, 1876, observed that "a limited view of the proper range of inquiry arose from the belief that the resistance must be as the square of the speed, and the horse-power as its cube; and that this belief, incorporated into one or other of the well-known constants, has survived more or less persistently in spite of attacks and misgivings, and has contributed a self-supported obstruction to new ideas."*

The diagram on the next page, based on Mr. Froude's experiments, shows that in this particular case the horse-power varied as the cube of the speed, plus a constant,—which scarcely varied between the speeds of 3 and 12 knots per hour. But the values of K and C must of course vary for each vessel; being dependent on the displacement, the cross-section, the skin resistance, the form of screw, &c.

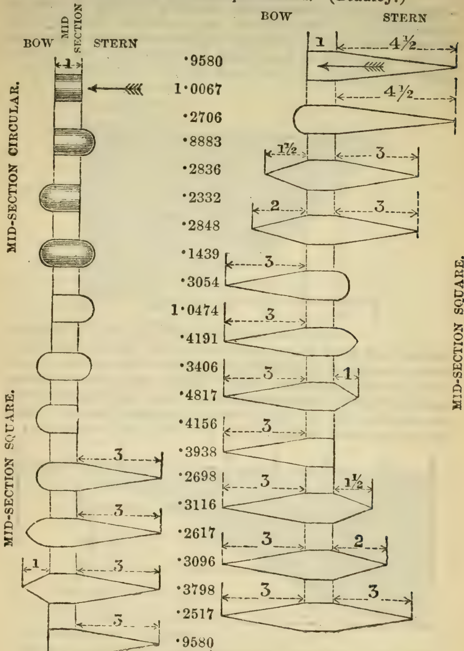
* Mr. Mansel has suggested an absolute constant $c = b\,V \log.^{-1} a\,V$, in which b involves one of the ordinary coefficients x, y, or z and the value of a is deduced from the tangent of the angle formed by the residues of $b - 2 \log. V$ at different trial speeds.

Propulsion of Vessels.

Diagram showing the coincidence of Formula $HP = V^3 K + C$ with Froude's experiments.

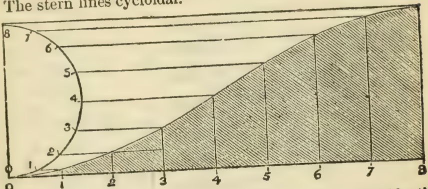


RELATIVE RESISTANCE OF SUBMERGED BODIES IN WATER, at a velocity of 1 foot per second. (Beaufoy.)

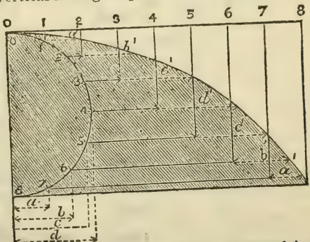


Wave Lines of Vessels.

The bow lines or entrance should be a curve of versed sines. The stern lines cycloidal.



To construct the curve of the entrance lines, divide the length into any number of equal parts and at each division erect perpendicular lines. At one end draw a semicircle with diameter = half the breadth of the vessel, divide the circumference into the same number of equal parts as the length, and from each division draw horizontal lines; their intersection with the vertical lines give points in the curve.



The cycloidal lines of the stern may be found in the same manner, but the horizontal lines must be prolonged beyond the points of intersection to a distance in each case equal to the horizontal distance of the circumference of the semicircle at that line from its perpendicular diameter. Thus the horizontal line at the intersection of the lines

1 and 1 must be prolonged to a distance $a' = a$.
2 and 2 " " " $b' = b$, &c.

WAVE LINES OF VESSELS—*continued.*

TABLE giving the Height of the Vertical Lines and the Length of Prolongation of the Horizontal Lines to form Cycloidal Curves, supposing the number of divisions to be 8, and the diameter of the semicircle = unity or 1·00.

At Division No.	1	2	3	4	5	6	7	8
Height of vertical	·03806	·14644	·30866	·5	·69134	·85355	·96194	1·0
Prolongation of horizontal	·19134	·3535	·4619	·5	·4619	·3535	·19134	—

A true cycloid may be constructed in the manner shown by the diagram in the preceding page, by making the length (or half the base of the cycloid) = diameter of the semicircle × 1·570796.

TABLE OF PROPORTION OF BOW AND STERN IN WAVE-LINE SHIPS. (For different Speeds.)

Bow = ·42 V^2. Stern = ·3 V^2.

Speed. Miles per Hour.	Length in feet of		Speed. Miles per Hour.	Length in feet of	
	Bow.	Stern.		Bow.	Stern.
1	·42	·3	11	50·81	36·3
2	1·68	1·2	12	60·48	43·2
3	3·78	2·7	13	70·98	50·7
4	6·72	4·8	14	82·32	58·8
5	10·50	7·5	15	94·50	67·5
6	15·12	10·8	16	107·52	76·8
7	20·58	14·7	17	121·38	86·7
8	26·88	19·2	18	136·08	97·2
9	34·02	24·3	19	151·62	108·3
10	42	30	20	168	120

Pressure of Water on an Oblique Surface relatively Narrow in the Line of Motion. (Lord Rayleigh.)

p = Normal pressure acting on the face of the plane.
P = Pressure of a head due to the speed acting on the plane.
a = Angle between the plane and the line of motion.

$$p = \frac{P\,(4 + \pi)\sin. a}{4 + \pi \sin. a}.$$

Froude is of opinion that as it appears by Beaufoy's experiments that when the plane is moving normally through the water so that $a = 90^\circ$ the resistance actually exceeds P in the ratio of 112 to 96, (or say 1·00 to ·86), it is not improbable that a proportionate excess beyond p as given in Lord Rayleigh's formula will be experienced when the motion is oblique.

Resistance of Vessels. (Froude.)

For moderate speeds, the resistance of a ship is proportional to the "indicated thrust" + a constant, which represents the dead-weight friction of the engines, &c.

The "indicated thrust" $= \dfrac{33{,}000\ P}{S\,n}$;

where P = Indicated horse-power,
S = Pitch of screw in feet,
n = Number of revolutions per minute.

From experiments with models, the following rule has been adduced:—

If the ship's dimensions be D times those of the model,
P = Indicated horse-power of the model,
V = Velocity of ditto;

then for speed $\sqrt{D}\,.\,V$ of the ship the power will be $D^3 P \sqrt{D}$. And if at speeds V_1, V_2, V_3, the measured resistances be R_1, R_2, and R_3 respectively, the resistances of the ship will be $D^3 R_1$; $D^3 R_2$; $D^3 R_3$ respectively.

In experiments with H.M.S. 'Greyhound,' it was found that about 58 per cent. of power was wasted in friction of machinery, and in detrimental action caused by the screw in the water at the stern of the vessel.

Lightening and thus diminishing the displacement did not seem to be proportionally advantageous.

Resistance of Vessels—*continued.*

Altering the trim of the vessel caused no great difference in the resistance. Superiority in resistance seems to be indicated in deep rather than in broad vessels.

It is calculated that the power is absorbed as follows, assuming the gross indicated horse-power = 1·000:—

Ship's net resistance	·426
Augmentation of ship's resistance by negative pressure caused by screw	·170
Water friction of screw	·043
Friction of engine	·143
Friction of working load	·143
Friction of air-pump and feed	·075
Total	1·000

or the proportion of gross indicated horse-power to effective horse-power as 2·347 to 1; and if to the gross indicated horse-power be added 10 per cent. for slip, the proportion will be 2·58, which nearly agrees with experiment.

In the experiments with H.M.S. 'Iris,' the following results were obtained:—

1. With twin four-bladed screws, a speed of 16·577 knots per hour was obtained with the expenditure of 7503 I.H.P.

2. On removing two of the blades of each screw, 15·726 knots per hour were obtained by the expenditure of only 4361 I.H.P.

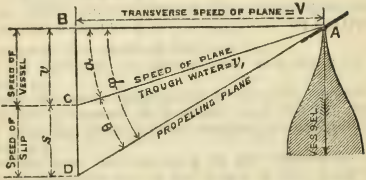
3. With new screws slightly modified in form from experiment No. 1, reduced in diameter about $\frac{1}{8}$th and pitch increased by about $\frac{1}{10}$th, 18·57 knots were obtained with 4572 I.H.P.

4. On removing two blades from each screw in No. 3, 18·59 knots were obtained with 7530 I.H.P.

The skin resistance is nearly as the area and V^2 (the square of the speed), but experiments approximate more nearly to $V^{1\cdot85}$ or $V^{1\cdot9}$ than to V^2.

At moderate speeds the resistance coincides with the calculated resistance due to surface friction alone; but as the speed increases, the entire resistance becomes more and more in excess of that due to surface friction. At low speed the frictional resistance of the engine is greater than the resistance of the ship.

Elementary Relation between Pitch, Slip, and Propulsive Efficiency. (Froude, 'Inst. Nav. Arch.,' 1878.)



A = Area of propelling plane surface in square feet.
P = Normal pressure on a plane area moving on a path forming the angle θ with the plane, in lbs.
p = Coefficient of pressure, lbs. per square foot = about 1·7.
f = " skin friction " = " ·008 (being ·004 for each surface).

$k = \frac{f}{p} =$ ·0047 appproximately.

F = Friction on surface of plane moving edgeways $= \text{A} f v^2$.
V = Speed of propeller plane, feet per second.
v = Speed of vessel in feet per second.
v_1 = Speed of plane through water, feet per second.
s = Speed of slip.
θ = Slip angle $= \sqrt{k}$ for maximum efficiency.
α = Virtual pitch angle.
ϕ = Actual " " $= \alpha + \theta$.
R = Propulsive force to maintain speed of ship, lbs.
W = Gross work done, foot-lbs.
w = Effective " " $= \text{R}\, v = \text{R V tan.}\, \alpha$.
E = Efficiency = W ÷ w = about ·77 as a maximum.

$$\text{Slip ratio} = \frac{s}{v+s}\,;\quad \text{P} = p\,\text{A}\,v^2 \sin.\theta\,;$$

$$\text{W} = p\,\text{A}\,\text{V}^3 \sec.^2 \alpha\,(\sin.\phi \sin.\theta + k \cos.\alpha);$$

$$\text{A} = \frac{\text{R}}{p\,v^2 \operatorname{cosec.}^2 \alpha\,(\cos.\phi \sin.\theta - k \sin.\alpha)}.$$

Relation between Pitch, Slip, and Efficiency—*continued.*

In these calculations the motion of water in the ship's wake has been disregarded, the action being assumed as if in undisturbed water.

The area which will drive a ship with a given "slip ratio" is directly as the vessel's resistance, and inversely as the square of the speed; and since at moderate speeds a ship's resistance is proportional to the square of the speed, the same area of propeller will at moderate speeds drive a given ship with the same slip ratio; and areas directly as the squares of the respective dimensions of two similar ships will drive with the same slip ratio, since the wetted surface measures the resistance in each case. At the higher speeds the slip ratio will increase with the given propelling area.

The maximum of efficiency is not produced by extending the area of the propelling plane so as to minimize the slip, but the slip angle that gives the maximum efficiency is moderate. If friction did not exist, the obliquity with which the propeller acts on the water would cause no loss in efficiency. The value of θ, which gives the maximum efficiency, is the same whatever be the value of ϕ. Although the slip angle ought to have the same value whatever be the pitch angle, the slip *ratio* will be greater for large pitch angles than for small. If the slip angle be that which gives the maximum efficiency, then to produce the maximum efficiency the propelling plane ought to stand at an angle of 45° with the line of ship's motion, whatever be the coefficient of surface friction or of normal pressure. If the slip angle exceed that which gives the maximum efficiency, the pitch angle must also be increased; if the excess be small, the pitch angle must be increased by the same amount; if the excess be large, the increment of pitch angle must be still greater.

The calculations point to the conclusion that a very much longer pitch than has commonly been adopted is favourable to efficiency; and that instead of its being correct to regard a large amount of slip as a proof of waste of power, the opposite conclusion is the true one. To assert that a screw works with unusually little slip, is to prove that it works with large waste of power.

Propulsion of Vessels. (Millar, 'Inst. Nav. Arch.,' 1877.)

"The reaction of the stream of water acted upon by any propelling instrument is the product of three factors:—

"(*a*) The mass of a cubic foot of water.
"(*b*) The number of cubic feet acted upon in a second.
"(*c*) The velocity in feet per second impressed on the water by the propeller."—*Rankine.*

V = Speed of the ship in feet per second.
P = " propeller in feet per second.
S = " stream driven back = P − V = the slip.
A* = *Effective* area of propeller in square feet.
N = Number of revolutions per second.
Q = Quantity of water acted upon in a second = A P.
g = Gravity = 32.
T = Thrust in lbs. propelling the ship.

$$= \frac{64\ A\ P}{g} = 2\ A\ P\ S \text{ for sea water.}$$

E = Energy expended = $A\ P\ S^2$ for sea water.

Thus while the thrust varies as the velocity, the lost work varies as the square of the velocity.

Slip of Paddle-wheels.

A = Length of arc of immersed portion of paddle-wheel (effective circumference).
C = Length of the chord of the arc immersed.
S = Slip of the wheel.

$$\frac{2\,(A - C)}{A} \text{ for radial floats.}$$

$$\frac{1{\cdot}5\,(A - C)}{A} \text{ for feathering floats.}$$

Approximately the slip of radial floats may be taken at 20 per cent., and of feathering floats at 15 per cent., on the effective circumference.

The effective circumference may be assumed to be that due to the extreme diameter, less $\frac{2}{3}$rds of the depth of a float.

* From experiments on the performance of some river steamers, it appears that only about one-half the actual area of one float on each paddle-wheel is effective.

PADDLE STEAMERS—*continued.*

IMMERSION OF FLOATS.

In large sea-steamers from 18 to 20 inches of water over the upper edge of float when vertical.

In small sea-steamers from 12 to 15 inches of water over the upper edge of float when vertical.

In river steamers 2 inches of water over the upper edge of float when vertical.

Number of floats immersed
= 4 in sea-going vessels.
= $1\frac{1}{2}$ to 2 in river steamers.

AREA OF FLOATS.

D = Diameter of paddle-wheels in feet.
A = Area of one float in feet.
P = Total indicated horse-power of engines.
L = Length of float in feet.

$A = \frac{P}{D}$ in ordinary sea-going vessels.

$A = \frac{\cdot 75\ P}{D}$ in fast vessels.

$L = 0 \cdot 6\ A$ in ordinary sea-going vessels.
$L = 0 \cdot 7\ A$ in fast vessels.

Distance of radial floats apart = $2\frac{1}{4}$ ft. in fast vessels.
" " " = 3 ft. in slow "
Distance of feathering floats apart = from 4 to 6 ft

PROPORTIONS OF PADDLE STEAMERS.

Length of keel	=	1·00
Breadth of beam	=	·14
Depth of vessel	=	·10
Centre of paddles from stern-post	=	·45

Screw Propellers.

RULE FOR THE SPEED OF SCREWS.

V = Velocity in knots per hour.
v = Velocity in *miles* per hour.
P = Pitch of screw in feet.
R = Number of revolutions per minute.

$$R = \frac{101\ V}{P}. \quad V = \frac{P\ R}{101}. \quad P = \frac{101\ V}{R}.$$

$$R = \frac{88\ v}{P}. \quad v = \frac{P\ R}{88}. \quad P = \frac{88\ v}{R}.$$

This is exclusive of the slip, which varies from 10 to 30 per cent.

Proportions of Screw Propellers.

PITCH OF SCREW.

The pitch of screws varies with the ratio of the circle described by the screw to the midship section.

FOR TWO-BLADED SCREWS.

Ratio of screw's disc to midship section being 1 to	6	5	4½	4	3½	3	2½	2
Ratio of pitch to the diameter of screw is 1 to	·8	1·02	1·11	1·2	1·27	1·31	1·4	1·47

For four-bladed screws multiply the ratio of the pitch to the diameter as given above by 1·35.

Length of screw = $\frac{1}{6}$th diameter of screw.

Multipliers for ascertaining the Stowage of Tallow, Waste, Oil, and Coal, in Coal-bunkers and Tanks for Steam Vessels:—

Tallow 59 lbs. in a cubic foot.
Waste 11 „ „
Oil 6·23 gallons in a cubic foot.
*Coal 45 cubic feet to a ton as stowed in coal-bunkers.

* Navy allowance: a ton may be stowed into a space of 4¾ cube feet.

Approximate Rule for the Speed of Screw Steamers.

HP = Total indicated horse-power.
V = Velocity of vessel in knots per hour.
S = Sectional area of midship section immersed, in square feet.
D = Displacement in tons.

$$V = \frac{1}{2}\left(\sqrt[3]{\frac{x\,\mathrm{HP}}{S}} + \sqrt[3]{\frac{k\,\mathrm{HP}}{\sqrt[3]{D^2}}}\right)$$

The Values of x and k are as follows: *—

	x	k
In fast troop-ships where the length is from 7 to $7\frac{1}{2}$ times the breadth amidships	750	260
In line-of-battle ships and frigates of deep immersion, where the length is 4 or $4\frac{1}{2}$ times the breadth	550	165
In frigates of lighter immersion, where the length is from 5 to $5\frac{1}{2}$ times the breadth	450	140
In gunboats of light immersion, where the length is about $6\frac{1}{2}$ times the breadth	430	150
In auxiliary line-of-battle ships, where the length is about $3\frac{1}{2}$ times the breadth	340	90

* The values of x and k have been deduced from the mean of a very large number of careful experiments with different vessels on trial,

x being $= \frac{V^3 S}{\mathrm{HP}}$ k being $= \frac{V^3 \sqrt[3]{D^2}}{\mathrm{HP}}$.

Approximate Rules for Paddle Steamers.

V = Velocity in knots per hour.
HP = Indicated horse-power (total).
S = Sectional area of ship in square feet (immersed).

$$V = \sqrt[3]{\frac{x\,HP}{S}}. \qquad HP = \frac{V^3\,S}{x}.$$

x = From 460 in small vessels not built for high speed.
= To 650 in small vessels with fine lines.
= 560 in large vessels not built for speed.
= 800 " " with fine lines.

Diameter of Paddle-wheels.

D = Effective diameter of paddle-wheel in feet.
d = Diameter of rolling circle of paddle-wheel in feet.
V = Velocity of ship in knots per hour.
v = Velocity in *miles* per hour.
R = Number of revolutions per minute.

$$d = \frac{32 \cdot 25\ V}{R}. \qquad D = \frac{45\ V}{R}. \qquad R = \frac{45\ V}{D}.$$

$$d = \frac{28\ v}{R}. \qquad D = \frac{39\ v}{R}. \qquad R = \frac{39\ v}{D}.$$

The diameter of paddle-wheels varies from 5 times the stroke of the engine in fast vessels to 3 times the stroke in slow.

Useful Memoranda for Steamships.

Cube feet of displacement × ·0279 = tons fresh water.
" " × ·0286 = tons sea water.
Miles × ·87 = knots.
Knots × 1·15 = miles.
Feet per minute × ·01 = knots per hour.
Lbs. of coal per hour × ·010714 = tons per 24 hours.
Indicated HP × ·01607 = tons of coal per 24 hours at rate of 1¼ lbs. per horse-power per hour.
" × ·02143 = ditto at 2 lbs.
" × ·02679 = ditto at 2½ lbs.

Tonnage of Vessels (New Measurement).

Divide the length of the upper deck between the after-part of the stem and the fore-part of the stern-post into 6 equal parts, and note the foremost, middle, and aftermost points of division. Measure the depths at these three points in feet and tenths of a foot; also the depths from the under-side of the upper deck to the ceiling of the limber-strake; or in case of a break in the upper deck, from a line stretched in continuation of the deck. For the breadths divide each depth into 5 equal parts, and measure the inside breadths at the following points, *viz.*:—At ·2 and ·8 from the upper deck of the foremost and aftermost depths; and from ·4 and ·8 from the upper deck of the amidship depth. Take the length at half the amidship depth from the after-part of the stem to the fore-part of the stern-post.

Then to twice the amidship depth add the foremost and aftermost depths for the *sum of the depths*, and add together the foremost upper and lower breadths 3 times the upper breadth with the lower breadth at the midship, and the upper and twice the lower breadth at the after division for the *sum of the breadths.*

Multiply together the sum of the depths, the sum of the breadths, and the length, and divide the product by 3500, which will give the number of tons or "register."

If the vessel has a poop or half-deck, or a break in the upper deck, measure the inside mean length, breadth, and height of such part thereof as may be included within the bulkhead; mul-

Tonnage of Vessels—*continued.*

tiply these three measurements together, and divide the product by 92·4; the quotient will be the number of tons to be added to the result as above ascertained.

For Open Vessels.—The depths are to be taken from the upper edge of the upper strake.

For Steam Vessels.—The tonnage due to the engine-room is deducted from the total tonnage computed by the above rule. To determine this, measure the inside of the engine-room from the foremost to the aftermost bulkhead; then multiply this length by the amidship depth of the vessel, and the product by the inside amidship breadth at ·4 of the depth from the deck, and divide the final product by 92·4.

Tonnage of Vessels (Builders' Measurement).

L = Length of keel between perpendiculars in ft.
B = Breadth of vessel in feet.

$$\text{Tonnage} = \frac{(L - \frac{3}{5}B) \times B \times \frac{1}{2}B}{94}.$$

The fore-perpendicular is taken at the fore-part of the stem at the height of the upper deck.

The aft-perpendicular is taken at the back of the stern-post at the height of the upper deck.

The middle deck is taken in three-deckers instead of the upper deck.

The breadth is taken as the extreme breadth at the height of the wales, subtracting the difference between the thickness of the wales and the bottom plank. Deductions to be made for the rake of the stem and stern.

TABLE FOR FACILITATING THE CALCULATION OF TONNAGE O. M. OR BUILDERS' TONNAGE. (By Oliver Byrne.)

Breadth of Beam.	Length to be Multiplied by	Constant, Subtract.	Breadth of Beam.	Length to be Multiplied by	Constant, Subtract.
feet.			feet.		
1	·00532	·0	41	8·94149	219·8
2	·02128	·0	42	9·38298	236·3
3	·04787	·1	43	9·83511	253·6
4	·08511	·2	44	10·29787	271·8
5	·13298	·4	45	10·77128	290·7
6	·19149	·7	46	11·25532	310·6
7	·26064	1·1	47	11·75000	331·3
8	·34043	1·6	48	12·25532	352·9
9	·43085	2·3	49	12·77128	375·4
10	·53191	3·2	50	13·29787	398·9
11	·64362	4·2	51	13·83511	423·3
12	·76596	5·5	52	14·38298	448·7
13	·89893	7·0	53	14·94149	475·1
14	1·04255	8·7	54	15·51064	502·5
15	1·19681	10·8	55	16·09043	531·0
16	1·36170	13·1	56	16·68085	560·5
17	1·53723	15·7	57	17·28191	591·0
18	1·72340	18·6	58	17·89362	622·7
19	1·92021	21·9	59	18·51596	655·5
20	2·12766	25·5	60	19·14894	689·4
21	2·34575	29·6	61	19·79255	724·4
22	2·57447	34·0	62	20·44681	760·6
23	2·81383	38·8	63	21·11170	798·0
24	3·06383	44·1	64	21·78723	836·6
25	3·32447	49·9	65	22·47340	876·4
26	3·59574	56·1	66	23·17021	917·5
27	3·87766	62·8	67	23·87766	959·8
28	4·17021	70·1	68	24·59574	1003·5
29	4·47340	77·8	69	25·32447	1048·4
30	4·78723	86·2	70	26·06383	1094·7
31	5·11170	95·1	71	26·81383	1142·2
32	5·44681	104·6	72	27·57447	1191·2
33	5·79255	114·7	73	28·34574	1241·5
34	6·14894	125·5	74	29·12766	1293·3
35	6·51596	136·9	75	29·92021	1346·4
36	6·89362	148·9	76	30·72340	1401·0
37	7·28191	161·7	77	31·53723	1457·0
38	7·68085	175·2	78	32·36170	1514·5
39	8·09043	189·4	79	33·19681	1573·5
40	8·51064	204·1	80	34·04255	1634·0

TONNAGE O. M. OR BUILDERS' TONNAGE—*continued.*

Breadth of Beam.	Length to be Multiplied by	Constant, Subtract.	Breadth of Beam.	Length to be Multiplied by	Constant, Subtract.
feet.			feet.		
81	34·89893	1696·1	91	44·04787	2405·1
82	35·76596	1759·7	92	45·02128	2485·2
83	36·64362	1824·8	93	46·00532	2567·2
84	37·53191	1891·6	94	47·00000	2650·8
85	38·43085	1960·0	95	48·00532	2736·3
86	39·34043	2030·0	96	49·02128	2823·6
87	40·26064	2101·6	97	50·04787	2912·8
88	41·19149	2174·9	98	51·08511	3003·8
89	42·13298	2249·9	99	52·13298	3096·7
90	43·08511	2326·6	100	53·19149	3191·5

This Table shows, in the second column, the tonnage per foot length of ship, according to the ordinary rule. Thus, 14 feet beam gives 1 ton per foot of length, 20 feet beam gives 2 tons per foot of length, 28 feet beam gives 4 tons, 31 feet 5 tons, 34 feet 6 tons, and so on for each foot in length; but this number is merely approximate, and wants correction. The third column supplies the correction, which is in tons, to be deducted. For example: Required the tonnage of a vessel whose length = 210 feet, breadth of beam = 39 feet:—

$$\begin{array}{r} 8{\cdot}09043 \times 210 = 1698{\cdot}99 \\ 189{\cdot}4 \\ \hline 1509{\cdot}59 = \text{Tonnage.} \end{array}$$

The Table has been computed from the following formula—

Tonnage B. O. M. =

$$\frac{(\lambda - \frac{3}{5}B) \times B \times \frac{1}{2}B}{94} = \frac{\frac{1}{2}\lambda B^2 - \frac{3}{10}B^3}{94} = \frac{1}{188}B^2 \times \lambda - \frac{3}{940}B^3,$$

λ being the length between perpendiculars expressed in feet, and B the extreme breadth in feet. The tonnage of a vessel of any dimensions, not given in the Table, may easily be calculated from either of the above expressions, with the help of a table of squares and cubes.

N.B. $\frac{1}{188} = 0{\cdot}00531\ 91489\ 36,$

$\frac{3}{940} = 0{\cdot}00319\ 14893\ 62.$

GUNNERY, &c. (Lieut. Percy B. Molesworth, R.E., from Major Mackinlay's Text-Book of Gunnery, 1887.)

GRAVIMETRIC DENSITY.

To find Gravimetric Density, G.D., of a charge.

Let S = cubic space allotted per lb. of powder in the chamber.

G.D. = Gravimetric Density.

$$G.D. = \frac{27 \cdot 73}{S}$$

WORK DONE BY EXPLODING POWDER.
(Table by Noble and Abel.)

Number of Expansions.	Work per lb. Burned.	Number of Expansions.	Work per lb. Burned.	Number of Expansions.	Work per lb. Burned.
	foot-tons.		foot-tons.		foot-tons.
1·25	19·226	5·5	95·210	11·0	121·165
1·50	31·986	6·0	98·638	12·0	124·239
1·75	41·494	6·5	101·744	13·0	127·036
2·0	49·050	7·0	104·586	14·0	129·602
2·5	60·642	7·5	107·192	15·0	131·970
3·0	69·347	8·0	109·600	16·0	134·168
3·5	76·315	8·5	111·840	17·0	136·218
4·0	82·107	9·0	113·937	18·0	138·138
4·5	87·064	9·5	115·905	19·0	139·944
5·0	91·385	10·0	117·757	20·0	141·647

This table is made out for charges of unit Gravimetric Density.

Divide cubic content of bore by cubic content of cartridge chamber, which will give number of expansions. Multiply number found opposite this in table by number of lbs. in charge, and result will be the work done.

If the charge be not of unit Gravimetric Density;

Suppose Gravimetric Density = ·8, and number of expansions = 5; Work done per lb. of powder

= Work done in 5 expansions—Work done in $\frac{1 \cdot 0}{\cdot 8}$, or 1·25 expansions.

= (91·385 − 19·226) foot-tons.

= 72·159 foot-tons.

In practice only a portion of this, called the factor of effect, varying from 0·7 to 0·9, is obtained. Thus, suppose factor of effect 0·8, the work realised is = 72·159 × 0·8 foot-tons.

= 57·727 foot-tons.

GUNNERY, &c.: WORK DONE BY EXPLODING POWDER—*continued.*

$\frac{w\,V^2}{2g \times 2240}$ foot tons is also a measure of the work contained in the projectile; in which w = weight of projectile in lbs.; V = the muzzle velocity in feet per second.

By equating these two expressions the probable muzzle velocity can be estimated before actual trial has been made.

STRENGTH OF GUNS.

Against a longitudinal burst:

$$P_2 = \frac{r_3^2 - r_2^2}{r_3^2 + r_2^2}\, t_2$$

$$P_1 = \frac{r_2^2 - r_1^2}{r_2^2 + r_1^2}\,(t_1 + P_2) + P_2$$

$$P_0 = \frac{r_1^2 - r_0^2}{r_1^2 + r_0^2}\,(t_0 + P_1) + P_1$$

in which P_0 P_1 P_2 are the pressures in tons per sq. in. at the surface of the bore, and at the surfaces of contact between the A tube and next outer piece, and between the latter and the outer cylinder.

t_0 t_1 t_2 are maximum hoop tensions in tons per sq. in. at the interiors of the same surfaces respectively on firing.

r_0 r_1 r_2 are the interior radii of the same three cylinders; r_1 and r_2 are also the exterior radii of the two inner portions; and r_3 is the exterior radius of the exterior cylinder.

If p is the maximum pressure which the metal of the bore can safely endure, and f is the factor of safety, $P_0 f = p$.

Against a circumferential burst or ring fracture:

A = area of cross section of bore in sq. inches.
A_1 = " " steel tube, in sq. inches.
A_2 = " " wrt. iron coils, in sq. ins.
f_1 = factor of safety of gun circumferentially.

$$A P_0 f_1 = 18\,A_1 + 10\,A_2$$

NOTE.—Guns of late design are entirely made of steel.

Gunnery, &c.: Trajectories.

Greatest height (H) of trajectory in feet is approximately $= T^2$ in which $T =$ total time of flight.

Flat Trajectories (Sladen's approximation.)

$$y = \frac{gt}{2}(T - t)$$

where $T =$ total time of flight

$t =$ time of flight to a point whose ordinate is y.

For mortars the parabolic theory may be accepted and the resistance of the air neglected for rough approximations.

Velocity and Momentum of Recoil.

If V = muzzle velocity of projectile.
W = weight of gun and carriage.
v = velocity " "
w = weight of projectile.
w_1 = weight of powder charge.

$$Wv = (w + Cw_1) V$$

where C is a constant deduced by experiment, usually rather less than unity.

Use of Bashforth's Tables (pp. 576, 577).

In using these tables put t = total time of flight.
T_V = number opposite velocity V in table (p. 576).
T_v = number opposite remaining velocity v in table (p. 576).

Similarly with the symbols s, S_V, S_v in table (p. 577).

In these tables d = diameter of bore in inches across the lands.
w = weight of projectile in lbs.

GUNNERY, &c. Bashforth's Time and Velocity Table. $\frac{d2}{w}t = T_V - T_v$.

Values of T_V and T_v in seconds.

Velocity. Feet per second.	0	10	20	30	40	50	60	70	80	90	Velocity. Feet per second.
800	225·768	226·021	226·267	226·504	226·734	226·955	227·169	227·375	227·575	227·768	800
900	227·954	228·135	228·309	228·478	228·641	228·799	228·953	229·101	229·245	229·385	900
1000	229·521	229·652	229·780	229·902	230·018	230·123	230·217	230·303	230·383	230·459	1000
1100	230·531	230·600	230·667	230·731	230.794	230·854	230·914	230·972	231·028	231·083	1100
1200	231·137	231·189	231·240	231·290	231·338	231·385	231·432	231·477	231·521	231·565	1200
1300	231·607	231.649	231·689	231·729	231·768	231·807	231·844	231·881	231·917	231·953	1300
1400	231·988	232·022	232·056	232·090	232·123	231·156	232·188	232·220	231·251	232·282	1400
1500	232·312	232·342	232·372	232·402	232·431	232·460	232.488	232·516	232·544	232·572	1500
1600	232·599	232·626	232·653	232·680	232·706	232·732	232·758	232·783	232·808	232·833	1600
1700	232·858	232·882	232·906	232·930	232·954	232·978	233·001	233·024	233·046	233·069	1700
1800	233·091	233·113	233·135	233·157	233·178	233·200	233·220	233·242	233·262	233·283	1800
1900	233·303	233·323	233·343	233·363	233·382	233·402	233·421	233·440	233.459	233·477	1900
2000	233·496	233·514	233·531	233·549	233·567	233·584	233·601	233·617	233·634	233·650	2000
2100	233·666	233·682	233·698	233·713	233·728	233·743	233·758	233·773	233·787	233·802	2100
2200	233·816	233·830	233·843	233·857	233·870	233·884	233·897	233·910	233·923	233·935	2200
2300	233·948	233·960	233·973	233·985	233·998	234·010	234·022	234·035	234·047	234·059	2300
2400	234·071	234·083	234·095	234·107	234·119	234·131	234·143	234·155	234·167	234·179	2400
Velocity. Feet per second.	0	10	20	30	40	50	60	70	80	90	Velocity. Feet per second.

GUNNERY, &c. Bashforth's Distance and Velocity Table. $\frac{d^2}{w} s = S_V - S_v$.

Values of S_V and S_v in Feet.

Velocity. Feet per Second.	0	10	20	30	40	50	60	70	80	90	Velocity. Feet per Second.
800	36512·6	36716·1	36916·0	37111·7	37303·1	37490·0	37672·4	37850·6	38024·8	38195·0	800
900	38361·5	38524·3	38683·5	38839·4	38991·9	39141·2	29287·4	39430·6	39570·8	39708·3	900
1000	39842·9	39975·0	40104·3	40230·1	40349·4	40459·2	40558·7	40650·5	40736·8	40819·0	1000
1100	40897·0	40974·2	41048·2	41120·5	41191·4	41261·0	41329·5	41396·8	41462·9	41528·0	1100
1200	41591·9	41654·8	41716·7	41777·5	41837·5	41896·5	41954·6	42011·8	42068·3	42123·9	1200
1300	42178·8	42233·0	42286·4	42339·2	42391·4	42443·0	42493·9	42544·4	42594·3	42643·7	1300
1400	42692·6	42741·2	42789·3	42837·1	42844·4	42931·4	42978·1	43024·5	43070·6	43116·4	1400
1500	43162·0	43207·2	43252·3	43297·2	43342·0	43386·5	43430·9	43475·1	43519·1	43563·0	1500
1600	43606·6	43650·0	43693·3	43736·3	43779·2	43831·9	33864·4	43906·8	43949·0	43990·9	1600
1700	44032·7	44074·3	44115·7	44157·0	44198·0	44238·9	44279·6	44320·2	44360·5	44400·7	1700
1800	44440·8	44480·6	44520·3	44559·8	44599·2	44638·4	44677·4	44716·3	44755·0	44793·7	1800
1900	44832·2	44870·5	44908·7	44946·7	44984·5	45022·2	45059·6	45096·9	45133·9	46170·6	1900
2000	45207·1	45243·3	45279·2	45314·9	45350·3	45385·4	45420·2	45454·7	45488·9	45522·8	2000
2100	45556·4	45589·7	45622·8	45655·5	45688·0	45720·2	45752·2	45783·9	45815·4	45846·6	2100
2200	45877·5	45908·3	45938·7	45969·0	45999·0	46028·7	46058·3	46087·6	46116·7	46145·7	2200
2300	46174·6	46203·5	46232·3	46261·2	46290·1	46319·0	46348·0	46377·0	46406·0	46435·1	2300
2400	46464·2	46493·4	46522·6	46551·9	46581·3	46610·6	46640·1	46669·5	46698·9	46728·4	2400
Velocity. Feet per Second.	0	10	20	30	40	50	60	70	80	90	Velocity. Feet per Second.

Gunnery, Etc.; Table of Penetrations.

Gun.	Rapidity of fire per min. Aimed Shots.	Brick. ft.	Earth. ft.	Oak. ft.	Charge of Piece.	Weight of Shot.	Thickness of Parapet. feet.	Muzzle Velocity. f. s.
M.H. Rifle	12	—	2	0·417	85 gr. R.F.G.	480 gr.	3	1370
Gatling	400–600	—						
9-Pr. M.L.	2	1·5	4	2	1 lb. 12 oz. R.L.G_2	9·65 lbs.	9	1380
16-Pr. M.L.	2	2	6	2½	3 lb. R.L.G_2	16 lbs.	9–12	1355
12-Pr. B.L.	3	Rather greater.			3 lb. 12 oz. P.	12·5 lbs.	9–12	1700
13-Pr. M.L.	2	Rather greater.			3 lb. 2 oz. R.L.G_2.	13·6 lbs.	9–12	1560

Multipliers.

Earths.		Woods.	
Very wet	0·87	Poplar	2·0
Sandy	1·00	Fir	1·8
Sand and Clay	1·09	Elm	1·3
Clay	1·44	Beech	1·0
Light earth	1·50	Ash	1·0
Recently turned	1·90		

Note.—It should be remembered that various causes will modify the above; when striking at an angle projectiles will deflect if the angle be sufficiently oblique.

Penetration of Armour. (Wrought Iron.)

Captain Orde Brown's rough rule: $v =$ striking velocity in feet per second.
$d =$ diameter of projectile in inches.

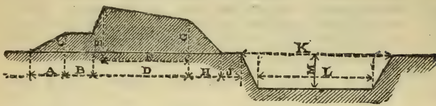
$$\text{Penetration in inches} = \frac{v\,d}{1000}.$$

Correction for Laying.

A gun laid by the ordinary sights carries to the side of the lowest wheel when the ground is uneven. With a field carriage, in which the wheels are about 60 inches apart, multiply the difference in level of the wheels in inches (or the inclination of the trunnions in degrees) by the number of degrees of elevation for the range, for the number of minutes of deflection to be given to the side of the highest wheel.

Sectional Area of Field Earthworks in Sq. Ft.

DIMENSIONS IN FEET.



Banquette.				Parapet.						Berm.	Ditch.			
A.	B.	C.	Sectional Area.	D.	E.	F.	G.	H.	Sectional Area.	J.	K.	L.	M.	Sectional Area.
			feet.						feet.					feet.
6	6	3	27	16·5	8	15	5·5	5·5	125	From 2 to 3 feet wide.	26	20	6	138
6	5	3	24	16·5	8	15	5	5	118·25		26	18	8	176
6	4	3	21	13·5	8	12	5·5	5·5	104·37		24	18	6	126
5	5	3	22·5	13·5	8	12	5	5	98·75		24	16	8	160
5	4	3	19·5	16·5	7·5	15	5·5	5·5	120·6		22	16	6	114
4	4	3	18	16·5	7·5	15	5	5	114·2		22	14	8	144
				13·5	7·5	12	5·5	5·5	101		20	14	6	102
				13·5	7·5	12	5	5	95·5		20	12	8	128
				10·5	7·5	9	5·5	5·5	81·6		18	12	6	90
				10·5	7·5	9	5	5	76·6		18	10	8	112
				7·5	7·5	6	5	5	58		16	10	8	104
				7·5	7·5	6	4·5	4·5	54		16	8	8	96
				5·5	7·5	4	5	5	45·5		14	8	6	66
				5·5	7·5	4	4·5	4·5	42		12	8	6	60
				7	6	6	4	4	42·5		10	4	6	42
				5	6	4	4	4	32·5		8	2	6	30

WEIGHTS AND MEASURES.

Avoirdupois Weight.

drachms.	ozs.	lbs.	qrs.	cwts.	ton.	French grammes.
1=	·0625=	·0039=	·000139=	·000035=	·00000174=	1·771846
16=	1=	·0625=	·00223 =	·000558=	·000028 =	28·34954
256=	16=	1 =	·0357 =	·00893 =	·000447 =	453·59
7168=	448=	28 =	1 =	·25 =	·0125 =	12,700
28672=	1792=	112 =	4 =	1 =	·05 =	50,802
573440=	35840=	2240 =	80 =	20 =	1 =	1,016,048

Troy Weight.

grains.	dwts.	ozs.	lb.	French grammes.
1=	·04167=	·00208=	·0001736=	·0648
24=	1 =	·05 =	·004167 =	1·555
480=	20 =	1 =	·0833 =	31·1035
5760=	240 =	12 =	1 =	373·242

175 lbs. troy = 144 lbs. avoirdupois.
lbs. avoirdupois × 1·2153 = lbs. troy.
lbs. troy .. × ·82286 = lbs. avoirdupois.

Long Measure.

ins.	feet.	yards.	fath.	poles.	furl.	mile.	French mètres.
1=	·083 =	·02778=	·0139=	·005 =	·000126=	·0000158=	·0254
12=	1 =	·333 =	·1667=	·0606=	·00151 =	·0001894=	·3048
36=	3 =	1 =	·5 =	·182 =	·00454 =	·000568 =	·9144
72=	6 =	2 =	1 =	·364 =	·0091 =	·001136 =	1·8287
198=	16½=	5½=	2¾=	1 =	·025 =	·003125 =	5·0291
7920=	660 =	220 =	110 =	40 =	1 =	·125 =	201·16
63360=	5280 =	1760 =	880 =	320 =	8 =	1 =	1609·315

WEIGHTS AND MEASURES—*continued.*

SURVEYING MEASURE (Lineal).

ins.	links.	feet.	yards.	chains.	mile.	French mètres.
1=	·126=	·0833=	·0278=	·00126=	·0000158=	·0254
7·92=	1 =	·66 =	·22 =	·01 =	·000125 =	·2012
12=	1·515=	1 =	·333 =	·01515=	·000189 =	·3048
36=	4·545=	3 =	1 =	·04545=	·000568 =	·9144
792=	100 =	66 =	22 =	1 =	·0125 =	20·116
63360=	8000 =	5280 =	1760 =	80 =	1 =	1609·315

1 knot or geographical mile = 6082·66 feet = 1854 mètres = 1·152 statute mile.

1 Admiralty knot = 1·1515 mile = 6080 feet, see pages **415** and **416.**

See Table of knots and miles.

SQUARE MEASURE.

ins.	feet.	yards.	perches.	roods.	acre.	square mètres.
1=	·00694 =	·000772=	·0000255=	·00000064=	·000000159=	·000645
144=	1 =	·111 =	·00367 =	·0000918 =	·000023 =	·0929
1296=	9 =	1 =	·0331 =	·000826 =	·0002062 =	·8361
39204=	272¼=	30¼ =	1 =	·025 =	·00625 =	25·292
1568160=	10890 =	1210 =	40 =	1 =	·25 =	1011·7
6272640=	43560 =	4840 =	160 =	4 =	1 =	4046·7

1 chain wide .. = 8 acres per mile.
10 square chains = 1 acre.
1 hectare .. = 2·471143 acres.

1 square mile $\begin{cases} = 27878400 \text{ sq. feet.} \\ = 3097600 \text{ sq. yards.} \\ = 640 \text{ acres.} \end{cases}$

Acres × ·0015625 = sq. miles.
Sq. yds. × ·000000323 = sq. miles.

CUBIC MEASURE.

ins.	feet.	yard.	cubic mètre, or stere.
1 =	·0005788 =	·000002144 =	·000016386
1728 =	1 =	·03704 =	·028315
46656 =	27 =	1 =	·764513

WEIGHTS AND MEASURES—*continued*

WINE MEASURE.

pints							
2 =	1 quart.						
8 =	4 =	1 gallon.					
336 =	168 =	42 =	1 tierce.				
504 =	252 =	63 =	$1\frac{1}{2}$ =	1 hogshead.			
672 =	336 =	84 =	2 =	$1\frac{1}{3}$ =	1 puncheon.		
1008 =	504 =	126 =	3 =	2 =	$1\frac{1}{2}$ =	1 pipe.	
2016 =	1008 =	252 =	6 =	4 =	3 =	2 =	1 tun

ALE AND BEER MEASURE.

pints								
2 =	1 quart.							
8 =	4 =	1 gallon.						
72 =	36 =	9 =	1 firkin.					
144 =	72 =	18 =	2 =	1 kilderkin.				
288 =	144 =	36 =	4 =	2 =	1 barrel.			
432 =	216 =	54 =	6 =	3 =	$1\frac{1}{2}$ =	1 hogshead.		
576 =	288 =	72 =	8 =	4 =	2 =	$1\frac{1}{3}$ =	1 puncheon.	
864 =	432 =	108 =	12 =	6 =	3 =	2 =	$1\frac{1}{2}$ =	1 butt.

MEASURE OF CAPACITY.

pints.	gall.	peck.	bushel.	quarter.	wey.	last.	cub. ft.	litres.
1 =	·125 =	·0625 =	·01562 =	·00195 =	·00039 =	·000195 =	·020051 =	·5679
8 =	1 =	·5 =	·125 =	·0156 =	·00312 =	·00156 =	·16046 =	4·543
16 =	2 =	1 =	·25 =	·03125 =	·00625 =	·00312 =	·32092 =	9·087
64 =	8 =	4 =	1 =	·125 =	·025 =	·0125 =	1·28367 =	36·34766
512 =	64 =	32 =	8 =	1 =	·2 =	·1 =	10·269 =	290·781
2560 =	320 =	160 =	40 =	5 =	1 =	·5 =	51·347 =	1453·906
5120 =	640 =	320 =	80 =	10 =	2 =	1 =	102·69 =	2907·81

1 gallon in wine, ale, or dry measure
= 277·27384 cubic inches = ·16 cubic foot
= 10 lbs. of distilled water =
Cube feet × 6·2355 = gallons.
Cube ins. × ·003607 = gallons.
1 bushel = 2218·19 cube inches = **1·28** cube foot.
Cube feet × ·78 = bushels.
Cube ins. × ·00045 = bushels.

Links reduced to Feet and Decimals (J. L. Gallott.)

Links.	Ft. Dec.	Links.	Ft. Dec.	Links.	Ft. Dec.
1	·66	36	23·76	71	46·86
2	1·32	37	24·42	72	47·52
3	1·98	38	25·08	73	48·18
4	2·64	39	25·74	74	48·84
5	3·30	40	26·40	75	49·50
6	3·96	41	27·06	76	50·16
7	4·62	42	27·72	77	50·82
8	5·28	43	28·38	78	51·48
9	5·94	44	29·04	79	52·14
10	6·60	45	29·70	80	52·80
11	7·26	46	30·36	81	53·46
12	7·92	47	31·02	82	54·12
13	8·58	48	31·68	83	54·78
14	9·24	49	32·34	84	55·44
15	9·90	50	33·00	85	56·10
16	10·56	51	33·66	86	56·76
17	11·22	52	34·32	87	57·42
18	11·88	53	34·98	88	58·08
19	12·54	54	35·64	89	58·74
20	13·20	55	36·30	90	59·40
21	13·86	56	36·96	91	60·06
22	14·52	57	37·62	92	60·72
23	15·18	58	38·28	93	61·38
24	15·84	59	38·94	94	62·04
25	16·50	60	39·60	95	62·70
26	17·16	61	40·26	96	63·36
27	17·82	62	40·92	97	64·02
28	18·48	63	41·58	98	64·68
29	19·14	64	42·24	99	65·34
30	19·80	65	42·90	100	66·00
31	20·46	66	43·56	200	132·00
32	21·12	67	44·22	300	198·00
33	21·78	68	44·88	400	264·00
34	22·44	69	45·54	500	330·00
35	23·10	70	46·20	600	396·00

Table of Knots and Statute Miles.

(Calculated by Lewis Olrick.)

The circumference of the earth is divided into 360 degrees, each degree containing 60 knots or nautical miles, consequently the circumference of the earth, *viz.* 131,385,456 feet divided by (360 × 60 =) 21,600 gives the length of a knot, *viz.* 6082·66 feet, which is generally considered the standard, except by the Admiralty.

1 knot = 6082·66 feet; 1 statute mile = 5280 feet.

1 degree = 60 knots = 69·121 miles.

Knots.	Miles.	Knots.	Miles.	Knots.	Miles.	Knots.	Miles.
1	1·152	7	8·064	13	14·976	19	21·888
1·25	1·440	7·25	8·352	13·25	15·264	19·25	22·176
1·50	1·728	7·50	8·640	13·50	15·552	19·50	22·464
1·75	2·016	7·75	8·928	13·75	15·840	19·75	22·752
2	2·304	8	9·216	14	16·128	20	23·040
2·25	2·592	8·25	9·504	14·25	16·416	20·25	23·328
2·50	2·880	8·50	9·792	14·50	16·704	20·50	23·616
2·75	3·168	8·75	10·080	14·75	16·992	20·75	23·904
3	3·456	9	10·368	15	17·280	21	24·192
3·25	3·744	9·25	10·656	15·25	17·568	21·25	24·480
3·50	4·032	9·50	10·944	15·50	17·856	21·50	24·768
3·75	4·320	9·75	11·232	15·75	18·144	21·75	25·056
4	4·608	10	11·520	16	18·432	22	25·344
4·25	4·896	10·25	11·808	16·25	18·720	22·25	25·632
4·50	5·184	10·50	12·096	16·50	19·008	22·50	25·920
4·75	5·472	10·75	12·384	16·75	19·296	22·75	26·208
5	5·760	11	12·672	17	19·584	23	26·496
5·25	6·048	11·25	12·960	17·25	19·872	23·25	26·784
5·50	6·336	11·50	13·248	17·50	20·160	23·50	27·072
5·75	6·624	11·75	13·536	17·75	20·448	23·75	27·360
6	6·912	12	13·824	18	20·736	24	27·648
6·25	7·200	12·25	14·112	18·25	21·024	24·25	27·936
6·50	7·488	12·50	14·400	18·50	21·312	24·50	28·224
6·75	7·776	12·75	14·688	18·75	21·600	24·75	28·512
						25	28·800

TABLE OF KNOTS AND STATUTE MILES—*continued.*

Miles.	Knots.	Miles.	Knots.	Miles.	Knots.	Miles.	Knots.
1	·868	8	6·944	15	13·020	22	19·096
1·25	1·085	8·25	7·161	15·25	13·237	22·25	19·313
1·50	1·302	8·50	7·378	15·50	13·454	22·50	19·530
1·75	1·519	8·75	7·595	15·75	13·671	22·75	19·747
2	1·736	9	7·812	16	13·888	23	19·964
2·25	1·953	9·25	8·029	16·25	14·105	23·25	20·181
2·50	2·170	9·50	8·246	16·50	14·322	23·50	20·398
2·75	2·387	9·75	8·463	16·75	14·539	23·75	20·615
3	2·604	10	8·680	17	14·756	24	20·832
3·25	2·821	10·25	8·897	17·25	14·973	24·25	21·049
3·50	3·038	10·50	9·114	17·50	15·190	24·50	21·266
3·75	3·255	10·75	9·331	17·75	15·407	24·75	21·483
4	3·472	11	9·548	18	15·624	25	21·700
4·25	3·689	11·25	9·765	18·25	15·841	25·25	21·917
4·50	3·906	11·50	9·982	18·50	16·058	25·50	22·134
4·75	4·123	11·75	10·199	18·75	16·275	25·75	22·351
5	4·340	12	10·416	19	16·492	26	22·568
5·25	4·557	12·25	10·633	19·25	16·709	26·25	22·785
5·50	4·774	12·50	10·850	19·50	16·926	26·50	23·002
5·75	4·991	12·75	11·067	19·75	17·143	26·75	23·219
6	5·208	13	11·284	20	17·360	27	23·436
6·25	5·425	13·25	11·501	20·25	17·577	27·25	23·653
6·50	5·642	13·50	11·718	20·50	17·794	27·50	23·870
6·75	5·859	13·75	11·935	20·75	18·011	27·75	24·087
7	6·076	14	12·152	21	18·228	28	24·304
7·25	6·293	14·25	12·369	21·25	18·445	28·25	24·521
7·50	6·510	14·50	12·586	21·50	18·662	28·50	24·738
7·75	6·727	14·75	12·803	21·75	18·879	28·75	24·955
						29	25·172

Table of Admiralty Knots and Statute Miles. (Calculated by Lewis Olrick.)

The Admiralty knot = 6080 feet; 1 statute mile = 5280 feet.

Knots.	Miles.	Knots.	Miles.	Knots.	Miles.	Knots.	Miles.
1	1·1515	7	8·0606	13	14·9696	19	21·8787
1·25	1·4394	7·25	8·3485	13·25	15·2575	19·25	22·1666
1·50	1·7272	7·50	8·6363	13·50	15·5454	19·50	22·4545
1·75	2·0151	7·75	8·9242	13·75	15·8332	19·75	22·7423
2	2·3030	8	9·2121	14	16·1212	20	23·0303
2·25	2·5909	8·25	9·5000	14·25	16·4091	20·25	23·3182
2·50	2·8787	8·50	9·7878	14·50	16·6969	20·50	23·6060
2·75	3·1666	8·75	10·0757	14·75	16·9848	20·75	23·8939
3	3·4545	9	10·3636	15	17·2727	21	24·1818
3·25	3·7424	9·25	10·6515	15·25	17·5606	21·25	24·4697
3·50	4·0303	9·50	10·9393	15·50	17·8484	21·50	24·7575
3·75	4·3181	9·75	11·2272	15·75	18·1363	21·75	25·0454
4	4·6060	10	11·5151	16	18·4242	22	25·3333
4·25	4·8939	10·25	11·8030	16·25	18·7121	22·25	25·6212
4·50	5·1818	10·50	12·0909	16·50	18·9999	22·50	25·9090
4·75	5·4696	10·75	12·3787	16·75	19·2878	22·75	26·1969
5	5·7575	11	12·6666	17	19·5757	23	26·4848
5·25	6·0454	11·25	12·9545	17·25	19·8636	23·25	26·7727
5·50	6·3333	11·50	13·2424	17·50	20·1515	23·50	27·0606
5·75	6·6211	11·75	13·5302	17·75	20·4393	23·75	27·3484
6	6·9090	12	13·8181	18	20·7272	24	27·6363
6·25	7·1969	12·25	14·1060	18·25	21·0151	24·25	27·9242
6·50	7·4848	12·50	14·3939	18·50	21·3030	24·50	28·2121
6·75	7·7726	12·75	14·6817	18·75	21·5908	24·75	28·4999
						25	28·7878

N.B.—The three first decimals in this Table are quite accurate, whereas the fourth cannot always be depended upon.

Table of Admiralty Knots and Statute Miles—*continued.*

Miles.	Knots.	Miles.	Knots.	Miles.	Knots.	Miles.	Knots.
1	·8684	8	6·9474	15	13·0263	22	19·1053
1·25	1·0855	8·25	7·1645	15·25	13·2434	22·25	19·3224
1·50	1·3026	8·50	7·3816	15·50	13·4605	22·50	19·5395
1·75	1·5197	8·75	7·5987	15·75	13·6776	22·75	19·7566
2	1·7368	9	7·8158	16	13·8947	23	19·9737
2·25	1·9539	9·25	8·0329	16·25	14·1118	23·25	20·1908
2·50	2·1710	9·50	8·2500	16·50	14·3289	23·50	20·4079
2·75	2·3881	9·75	8·4671	16·75	14·5460	23·75	20·6250
3	2·6053	10	8·6842	17	14·7632	24	20·8421
3·25	2·8224	10·25	8·9013	17·25	14·9803	24·25	21·0592
3·50	3·0395	10·50	9·1184	17·50	15·1974	24·50	21·2763
3·75	3·2566	10·75	9·3355	17·75	15·4145	24·75	21·4934
4	3·4737	11	9·5526	18	15·6316	25	21·7105
4·25	3·6908	11·25	9·7697	18·25	15·8487	25·25	21·9276
4·50	3·9079	11·50	9·9868	18·50	16·0658	25·50	22·1447
4·75	4·1250	11·75	10·2039	18·75	16·2829	25·75	22·3618
5	4·3421	12	10·4211	19	16·5000	26	22·5789
5·25	4·5592	12·25	10·6382	19·25	16·7171	26·25	22·7960
5·50	4·7763	12·50	10·8553	19·50	16·9342	26·50	23·0131
5·75	4·9934	12·75	11·0724	19·75	17·1513	26·75	23·2302
6	5·2105	13	11·2895	20	17·3684	27	23·4474
6·25	5·4276	13·25	11·5066	20·25	17·5855	27·25	23·6645
6·50	5·6447	13·50	11·7237	20·50	17·8026	27·50	23·8816
6·75	5·8618	13·75	11·9408	20·75	18·0197	27·75	24·0987
7	6·0789	14	12·1579	21	18·2368	28	24·3158
7·25	6·2960	14·25	12·3750	21·25	18·4539	28·25	24·5329
7·50	6·5131	14·50	12·5921	21·50	18·6710	28·50	24·7500
7·75	6·7302	14·75	12·8092	21·75	18·8881	28·75	24·9671
						29	25·1842

N.B.—The three first decimals in this Table are quite accurate, whereas the fourth cannot always be depended upon.

Decimal Equivalents of the Divisions of a Foot.

(Communicated by J. Gallott, Esq.) For divisions in 32nds, see next page.

	0	1	2	3	4	5	6	7	8	9	10	11
		·08333	·16666	·25	·33333	·41666	·5	·58333	·66666	·75	·83333	·91666
$\frac{1}{16}$	·00521	·08854	·17187	·25521	·33854	·42187	·50521	·58854	·67187	·75521	·83854	·92187
$\frac{1}{8}$	·01041	·09374	·17707	·26041	·34374	·42707	·51041	·59374	·67707	·76041	·84374	·92707
$\frac{3}{16}$	·01562	·09895	·18228	·26562	·34895	·43228	·51562	·59895	·68228	·76562	·84895	·93228
$\frac{1}{4}$	·02083	·10416	·18750	·27083	·35416	·43750	·52083	·60416	·68750	·77083	·85416	·93750
$\frac{5}{16}$	·02604	·10937	·19270	·27604	·35937	·44270	·52604	·60937	·69270	·77604	·85937	·94270
$\frac{3}{8}$	·03125	·11458	·19791	·28125	·36458	·44791	·53125	·61458	·69791	·78125	·86458	·94791
$\frac{7}{16}$	·03646	·11979	·20312	·28646	·36979	·45312	·53646	·61979	·70312	·78646	·86979	·95312
$\frac{1}{2}$	·04166	·12500	·20832	·29166	·37500	·45833	·54166	·62500	·70832	·79166	·87500	·95833
$\frac{9}{16}$	·04687	·13020	·21353	·29687	·38020	·46353	·54687	·63020	·71353	·79687	·88020	·96353
$\frac{5}{8}$	·05208	·13541	·21874	·30208	·38541	·46875	·55208	·63541	·71874	·80208	·88541	·96875
$\frac{11}{16}$	·05729	·14062	·22395	·30729	·39062	·47395	·55729	·64062	·72395	·80729	·89062	·97395
$\frac{3}{4}$	·06250	·14583	·22916	·31250	·39583	·47916	·56250	·64583	·72916	·81250	·89583	·97916
$\frac{13}{16}$	·06771	·15104	·23437	·31771	·40104	·48437	·56771	·65104	·73437	·81771	·90104	·98437
$\frac{7}{8}$	·07292	·15625	·23958	·32292	·40625	·48958	·57292	·65625	·73958	·82292	·90625	·98958
$\frac{15}{16}$	·07813	·16146	·24479	·32813	·41146	·49479	·57813	·66146	·74479	·82813	·91146	·99479

Decimal Equivalents of the Divisions of a Foot in 32nds of an Inch.

(For the divisions in 16ths, see preceding page.)

	Inches. 0	Inches. 1	Inches. 2	Inches. 3	Inches. 4	Inches. 5	Inches. 6	Inches. 7	Inches. 8	Inches. 9	Inches. 10	Inches. 11	
	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	
$\frac{1}{32}$	·00260	·08594	·16927	·25260	·33594	·41927	·50260	·58594	·66927	·75260	·83594	·91927	$\frac{1}{32}$
$\frac{3}{32}$	·00781	·09114	·17448	·25781	·34114	·42448	·50781	·59114	·67448	·75781	·84114	·92448	$\frac{3}{32}$
$\frac{5}{32}$	·01302	·09635	·17969	·26302	·34635	·42969	·51302	·59635	·67969	·76302	·84635	·92969	$\frac{5}{32}$
$\frac{7}{32}$	·01823	·10156	·18489	·26823	·35156	·43489	·51823	·60156	·68489	·76823	·85156	·93489	$\frac{7}{32}$
$\frac{9}{32}$	·02344	·10677	·19010	·27344	·35677	·44010	·52344	·60677	·69010	·77344	·85677	·94010	$\frac{9}{32}$
$\frac{11}{32}$	·02864	·11198	·19531	·27864	·36198	·44531	·52864	·61198	·69531	·77864	·86198	·94531	$\frac{11}{32}$
$\frac{13}{32}$	·03385	·11719	·20052	·28385	·36719	·45052	·53385	·61719	·70052	·78385	·86719	·95052	$\frac{13}{32}$
$\frac{15}{32}$	·03906	·12239	·20573	·28906	·37239	·45573	·53906	·62239	·70573	·78906	·87239	·95573	$\frac{15}{32}$
$\frac{17}{32}$	·04427	·12760	·21094	·29427	·37760	·46094	·54427	·62760	·71094	·79427	·87760	·96094	$\frac{17}{32}$
$\frac{19}{32}$	·04948	·13281	·21614	·29948	·38281	·46614	·54948	·63281	·71614	·79948	·88281	·96614	$\frac{19}{32}$
$\frac{21}{32}$	·05469	·13802	·22135	·30469	·38802	·47135	·55469	·63802	·72135	·80469	·88802	·97135	$\frac{21}{32}$
$\frac{23}{32}$	·05989	·14323	·22656	·30989	·39323	·47656	·55989	·64323	·72656	·80989	·89323	·97656	$\frac{23}{32}$
$\frac{25}{32}$	·06510	·14844	·23177	·31510	·39844	·48177	·56510	·64844	·73177	·81510	·89844	·98177	$\frac{25}{32}$
$\frac{27}{32}$	·07031	·15364	·23698	·32031	·40364	·48698	·57031	·65364	·73698	·82031	·90364	·98698	$\frac{27}{32}$
$\frac{29}{32}$	·07552	·15885	·24219	·32552	·40885	·49219	·57552	·65885	·74219	·82552	·90885	·99219	$\frac{29}{32}$
$\frac{31}{32}$	·08073	·16406	·24739	·33073	·41406	·49739	·58073	·66406	·74739	·83073	·91406	·99739	$\frac{31}{32}$
	0	1	2	3	4	5	6	7	8	9	10	11	

Decimal Equivalents of Inches, Feet, and Yards.

Fractions of an Inch.	Decims. of an Inch.	$\frac{1}{32}$nds.	Decims. of an Inch.
	·0625	1 =	·03125
$\frac{1}{8}$	·125	3 =	·09375
	·1875	5 =	·15625
$\frac{1}{4}$	·25	7 =	·21875
	·3125	9 =	·28125
$\frac{3}{8}$	·375	11 =	·34375
	·4375	13 =	·40625
$\frac{1}{2}$	·5	15 =	·46875
	·5625	17 =	·53125
$\frac{5}{8}$	·625	19 =	·59375
	·6875	21 =	·65625
$\frac{3}{4}$	·75	23 =	71875
	·8125	25 =	78125
$\frac{7}{8}$	·875	27 =	·84375
	·9375	29 =	·90625
1 inch	1·00	31 =	·96875

Inches.	Feet.	Yards.
1 =	·0833 =	·0278
2 =	·1667 =	·0556
3 =	·25 =	·0833
4 =	·3333 =	·1111
5 =	·4167 =	·1389
6 =	·5 =	·1667
7 =	·5833 =	1944
8 =	·6667 =	·2222
9 =	·75 =	·25
10 =	·8333 =	·2778
11 =	·9167 =	·3056
12 =	1·000 =	·3333

Timber Measuring.

G = $\frac{1}{4}$th girt of tree at middle in feet.
g = $\frac{1}{4}$th girt of tree at one end in feet.
g' = $\frac{1}{4}$th girt of tree at the other end in feet.
L = Length of log in feet.
c = Cube contents of log in feet.

$$c = \mathrm{L}\left(\frac{\mathrm{G} + g + g'}{3}\right)^2.$$

Allowance is to be made for bark by deducting from each $\frac{1}{4}$th girt. The allowance varies from half an inch in trees with thin bark to 2 inches for trees with thick bark.

Measures of Timber.

100 superficial feet of planking .. = 1 square.
120 deals .. .. = 1 hundred
50 cube feet of squared timber .. = 1 load.
40 feet of unhewn timber .. .. = 1 load.
600 superficial ft. of inch planking = 1 load.
Boards 7 inches wide .. .. .. = battens.
„ 9 „ .. .. .. = deals.
„ 12 „ .. .. .. = planks.

Sundry Measures.

A stone = 14 lbs.
A score = 20.
A gross = 12 dozen.
A quire = 24 sheets.
A ream = 20 quires.
A cord of wood = 128 cube feet.
A seam of glass = 120 lbs.
A faggot of steel = 120 lbs.
A ton of coal = 10 sacks.
A ton of Portland cement = **10** sacks or 6 casks.
A barrel of tar = 25 gallons.
A ton of freight by measurement = 40 cubic feet.

Size of Drawing Paper.

	Inches.		Inches.
Demy	20 by 15	Atlas	34 by 26
Medium	22 „ 17	Double Elephant	40 „ 27
Royal	24 „ 19	Antiquarian ..	52 „ 31
Super-royal	27 „ 19	Tracing paper ..	30 „ 20
Imperial	30 „ 22	„ ..	30 „ 40
Columbier	34 „ 23	„ ..	60 „ 40

Tracing cloth, 18, 28, 36, 38, and 41 inches wide; 24 yards long.
Continuous cartridge, 54 and 60 inches wide.

Casks. (J. T. Hurst.)

D, d = inside diameters at the heads.

M = ditto at the bung, and L = the length, all in inches; then

The capacity in imperial gallons

$$= \cdot 0014162\, L\, (D\, d + M^2).$$

The Buoyancy in lbs. equals ten times the capacity in gallons *minus* the weight of the cask itself.

WIRE AND PLATE GAUGES. (Equivalents in Decimals of an Inch):—For Telegraph Wire Gauge, see Telegraph.

No.	New Standard Wire Gauge.	Birmingham Plate.	Lancashire.	Whitworth.	French Wire. Ordinary.		French Wire. Galvanized.	
	ins	ins.	ins.		ins.	mm.	ins.	mm.
7/0	0·500	—	—	—	—	—	—	—
6/0	0·464	—	—	—	—	—	—	—
5/0	0·432	—	—	—	—	—	—	—
4/0	0·400	—	—	—	—	—	—	—
3/0	0·372	—	—	—	—	—	—	—
2/0	0·348	—	—	—	—	—	—	—
0	0·324	—	—	—	·01535	·39	—	—
1	0·300	·004	·227	·001	·01772	·45	·02362	·6
2	0·276	·005	·219	·002	·02205	·56	·02756	·7
3	0·252	·008	·209	·003	·02638	·67	·03150	·8
4	0·232	·010	·204	·004	·03110	·79	·03543	·9
5	0·212	·012	·201	·005	·03543	·90	·03937	1·0
6	0·192	·013	·198	·006	·03976	1·01	·04331	1·1
7	0·176	·015	·195	·007	·04410	1·12	·04724	1·2
8	0·160	·016	·192	·008	·04882	1·24	·05118	1·3
9	0·144	·019	·191	·009	·05315	1·35	·05512	1·4
10	0·128	·024	·190	·010	·05748	1·46	·05906	1·5
11	0·116	·029	·189	·011	·06614	1·68	·06299	1·6
12	0·104	·034	·185	·012	·07087	1·80	·07087	1·8
13	0·092	·036	·180	·013	·07520	1·91	·07874	2·0
14	0·080	·041	·177	·014	·07953	2·02	·08662	2·2
15	0·072	·047	·175	·015	·08425	2·14	·09449	2·4
16	0·064	·051	·174	·016	·08858	2·25	·10630	2·7
17	0·056	·057	·169	·017	·11181	2·84	·11811	3·0
18	0·048	·061	·167	·018	·13386	3·40	·13386	3·4
19	0·040	·064	·164	·019	·15551	3·95	·15355	3·9
20	0·036	·067	·160	·020	·17717	4·50	·17323	4·4
21	0·032	·072	·157	·021	·20079	5·10	·19292	4·9
22	0·028	·074	·152	·022	·22244	5·65	·21260	5·4
23	0·024	·077	·150	·023	·24410	6·20	·23229	5·9
24	0·022	·082	·148	·024	·26772	6·80	—	—
25	0·020	·095	·146	·025				
26	0·018	·103	·143	·026				
27	0·0164	·113	·141	·027				
28	0·0148	·120	·138	·028				
29	0·0136	·124	·134	·029				
30	0·0124	·126	·125	·030				
31	0·0116	·133	·118	·031				
32	0·0108	·143	·115	·032				
33	0·0100	·145	·111	·033				
34	0·0092	·148	·109	·034				
35	0·0084	·158	·107	·035				

N. S. W. G.—*continued.*

No.	S. W. G.	No.	S. W. G.
	ins.		ins.
37	0·0068	44	0·0032
38	0·0060	45	0·0028
39	0·0052	46	0·0024
40	0·0048	47	0·0020
41	0·0044	48	0·0016
42	0·0040	49	0·0012

TABLE OF CUBIC FEET EQUIVALENT TO IMPERIAL GALLONS.

Gallons.	0	1	2	3	4	5	6	7	8	9	Gallons.
0	—	·16046	·32092	·48138	·64184	·80230	·96276	1·12322	1·28368	1·44414	0
10	1·60460	1·76505	1·92551	2·08597	2·24643	2·40689	2·56735	2·72781	2·88827	3·04873	10
20	3·20919	3·36965	3·53011	3·69057	3·85103	4·01149	4·17195	4·33241	4·49287	4·65333	20
30	4·81379	4·97424	5·13470	5·29516	5·45562	5·61608	5·77654	5·93700	6·09746	6·25792	30
40	6·41838	6·57884	6·73930	6·89976	7·06022	7·22068	7·38114	7·54160	7·70206	7·86252	40
50	8·02298	8·18343	8·34389	8·50435	8·66481	8·82527	8·98573	9·14619	9·30665	9·46711	50
60	9·62757	9·78803	9·94849	10·10895	10·26941	10·42987	10·59033	10·75079	10·91125	11·07171	60
70	11·23216	11·39262	11·55308	11·71354	11·87400	12·03446	12·19492	12·35538	12·51584	12·67630	70
80	12·83676	12·99722	13·15768	13·31814	13·47860	13·63906	13·79952	13·95998	14·12044	14·28090	80
90	14·44136	14·60181	14·76227	14·92273	15·08319	15·24365	15·40411	15·56457	15·72503	15·88549	90
Gallons.	0	1	2	3	4	5	6	7	8	9	Gallons.

Decimal Equivalents of Lbs., Qrs., and Cwts.

qrs.	lbs.	cwts.	qrs.	lbs.	cwts.	qrs.	lbs.	cwts.	qrs.	lbs.	cwts.
0	0½ =	·0045	1	0 =	·25	2	0 =	·5	3	0 =	·75
0	1	·0089	1	1	·2589	2	1	·5089	3	1	·7589
0	2	·0179	1	2	·2679	2	2	·5179	3	2	·7679
0	3	·0268	1	3	·2768	2	3	·5268	3	3	·7768
0	4	·0357	1	4	·2857	2	4	·5357	3	4	·7857
0	5	·0446	1	5	·2946	2	5	·5446	3	5	·7946
0	6	·0536	1	6	·3036	2	6	·5536	3	6	·8036
0	7	·0625	1	7	·3125	2	7	·5625	3	7	·8125
0	8	·0714	1	8	·3214	2	8	·5714	3	8	·8214
0	9	·0803	1	9	·3303	2	9	·5803	3	9	·8303
0	10	·0893	1	10	·3393	2	10	·5893	3	10	·8393
0	11	·0982	1	11	·3482	2	11	·5982	3	11	·8482
0	12	·1071	1	12	·3571	2	12	·6071	3	12	·8571
0	13	·1161	1	13	·3661	2	13	·6161	3	13	·8661
0	14	·125	1	14	·375	2	14	·625	3	14	·875
0	15	·1339	1	15	·3839	2	15	·6339	3	15	·8839
0	16	·1429	1	16	·3929	2	16	·6429	3	16	·8929
0	17	·1518	1	17	·4018	2	17	·6518	3	17	·9018
0	18	·1607	1	18	·4107	2	18	·6607	3	18	·9107
0	19	·1696	1	19	·4196	2	19	·6696	3	19	·9196
0	20	·1786	1	20	·4286	2	20	·6786	3	20	·9286
0	21	·1875	1	21	·4375	2	21	·6875	3	21	·9375
0	22	·1964	1	22	·4464	2	22	·6964	3	22	·9464
0	23	·2054	1	23	·4554	2	23	·7054	3	23	·9554
0	24	·2143	1	24	·4643	2	24	·7143	3	24	·9643
0	25	·2232	1	25	·4732	2	25	·7232	3	25	·9732
0	26	·2322	1	26	·4822	2	26	·7322	3	26	·9822
0	27	·2411	1	27	·4911	2	27	·7411	3	27	·9911

Decimal Equivalents of Pounds and Ounces.

ozs.	lbs.	ozs.	lbs.	ozs.	lbs.	ozs.	lbs.	ozs.	lbs.
¼	·015625	3	·1875	6½	·40625	10	·625	13½	·84375
½	·03125	3½	·21875	7	·4375	10½	·65625	14	·875
¾	·046875	4	·25	7½	·46875	11	·6875	14½	·90625
1	·0625	4½	·28125	8	·5	11½	·71875	15	·9375
1½	·09375	5	·3125	8½	·53125	12	·75	15½	·96875
2	·125	5½	·34375	9	·5625	12½	·78125	16	1·0
2½	·15625	6	·375	9½	·59375	13	·8125		

Table showing Equivalent Rates per Lb., Cwt., and Ton.

Per lb.	Per cwt.		Per ton.			Per lb.	Per cwt.		Per ton.		
d.	s.	d.	£.	s.	d.	d.	s.	d.	£.	s.	d.
¼	2	4	2	6	8	6¼	58	4	58	6	8
½	4	8	4	13	4	6½	60	8	60	13	4
¾	7	0	7	0	0	6¾	63	0	63	0	0
1	9	4	9	6	8	7	65	4	65	6	8
1¼	11	8	11	13	4	7¼	67	8	67	13	4
1½	14	0	14	0	0	7½	70	0	70	0	0
1¾	16	4	16	6	8	7¾	72	4	72	6	8
2	18	8	18	13	4	8	74	8	74	13	4
2¼	21	0	21	0	0	8¼	77	0	77	0	0
2½	23	4	23	6	8	8½	79	4	79	6	8
2¾	25	8	25	13	4	8¾	81	8	81	13	4
3	28	0	28	0	0	9	84	0	84	0	0
3¼	30	4	30	6	8	9¼	86	4	86	6	8
3½	32	8	32	13	4	9½	88	8	88	13	4
3¾	35	0	35	0	0	9¾	91	0	91	0	0
4	37	4	37	6	8	10	93	4	93	6	8
4¼	39	8	39	13	4	10¼	95	8	95	13	4
4½	42	0	42	0	0	10½	98	0	98	0	0
4¾	44	4	44	6	8	10¾	100	4	100	6	8
5	46	8	46	13	4	11	102	8	102	13	4
5¼	49	0	49	0	0	11¼	105	0	105	0	0
5½	51	4	51	6	8	11½	107	4	107	6	8
5¾	53	8	53	13	4	11¾	109	8	109	13	4
6	56	0	56	0	0	12	112	0	112	0	0

Decimal Equivalents of Pence and Shillings.

Pence.	Shillings.	Pence.	Shillings.	Pence.	Shillings.
½ .. =	·04166	4½ .. =	·3750	8½ .. =	·70832
1 .. =	·08333	5 .. =	·41666	9 .. =	·75
1½ .. =	·125	5½ .. =	·45833	9½ .. =	·79166
2 .. =	·16666	6 .. =	·5	10 .. =	·83333
2½ .. =	·20832	6½ .. =	·54166	10½ .. =	·8750
3 .. =	·25	7 .. =	·58333	11 .. =	·91666
3½ .. =	·29166	7½ .. =	·6250	11½ .. =	·95833
4 .. =	·33333	8 .. =	·66666	12 .. =	1·0000

READY RECKONER.

1	2	3	4	5	6	7	8	9	10
d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.
¼	0 0½	0 0¾	0 1	0 1¼	0 1½	0 1¾	0 2	0 2¼	0 2½
½	0 1	0 1½	0 2	0 2½	0 3	0 3½	0 4	0 4½	0 5
¾	0 1½	0 2¼	0 3	0 3¾	0 4½	0 5¼	0 6	0 6¾	0 7½
1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	0 10
1¼	0 2½	0 3¾	0 5	0 6¼	0 7½	0 8¾	0 10	0 11¼	1 0½
1½	0 3	0 4½	0 6	0 7½	0 9	0 10½	1 0	1 1½	1 3
1¾	0 3½	0 5¼	0 7	0 8¾	0 10½	1 0¼	1 2	1 3¾	1 5½
2	0 4	0 6	0 8	0 10	1 0	1 2	1 4	1 6	1 8
2¼	0 4½	0 6¾	0 9	0 11¼	1 1½	1 3¾	1 6	1 8¼	1 10½
2½	0 5	0 7½	0 10	1 0½	1 3	1 5½	1 8	1 10½	2 1
2¾	0 5½	0 8¼	0 11	1 1¾	1 4½	1 7¼	1 10	2 0¾	2 3½
3	0 6	0 9	1 0	1 3	1 6	1 9	2 0	2 3	2 6
3¼	0 6½	0 9¾	1 1	1 4¼	1 7½	1 10¾	2 2	2 5¼	2 8½
3½	0 7	0 10½	1 2	1 5½	1 9	2 0½	2 4	2 7½	2 11
3¾	0 7½	0 11¼	1 3	1 6¾	1 10½	2 2¼	2 6	2 9¾	3 1½
4	0 8	1 0	1 4	1 8	2 0	2 4	2 8	3 0	3 4
4¼	0 8½	1 0¾	1 5	1 9¼	2 1½	2 5¾	2 10	3 2¼	3 6½
4½	0 9	1 1½	1 6	1 10½	2 3	2 7½	3 0	3 4½	3 9
4¾	0 9½	1 2¼	1 7	1 11¾	2 4½	2 9¼	3 2	3 6¾	3 11½
5	0 10	1 3	1 8	2 1	2 6	2 11	3 4	3 9	4 2
5¼	0 10½	1 3¾	1 9	2 2¼	2 7½	3 0¾	3 6	3 11¼	4 4½
5½	0 11	1 4½	1 10	2 3½	2 9	3 2½	3 8	4 1½	4 7
5¾	0 11½	1 5¼	1 11	2 4¾	2 10½	3 4¼	3 10	4 3¾	4 9½
6	1 0	1 6	2 0	2 6	3 0	3 6	4 0	4 6	5 0
6¼	1 0½	1 6¾	2 1	2 7¼	3 1½	3 7¾	4 2	4 8¼	5 2½
6½	1 1	1 7½	2 2	2 8½	3 3	3 9½	4 4	4 10½	5 5
6¾	1 1½	1 8¼	2 3	2 9¾	3 4½	3 11¼	4 6	5 0¾	5 7½
7	1 2	1 9	2 4	2 11	3 6	4 1	4 8	5 3	5 10
7¼	1 2½	1 9¾	2 5	3 0¼	3 7½	4 2¾	4 10	5 5¼	6 0½
7½	1 3	1 10½	2 6	3 1½	3 9	4 4½	5 0	5 7½	6 3
7¾	1 3½	1 11¼	2 7	3 2¾	3 10½	4 6¼	5 2	5 9¾	6 5½
8	1 4	2 0	2 8	3 4	4 0	4 8	5 4	6 0	6 8
8¼	1 4½	2 0¾	2 9	3 5¼	4 1½	4 9¾	5 6	6 2¼	6 10½
8½	1 5	2 1½	2 10	3 6½	4 3	4 11½	5 8	6 4½	7 1
8¾	1 5½	2 2¼	2 11	3 7¾	4 4½	5 1¼	5 10	6 6¾	7 3½
9	1 6	2 3	3 0	3 9	4 6	5 3	6 0	6 9	7 6
9¼	1 6½	2 3¾	3 1	3 10¼	4 7½	5 4¾	6 2	6 11¼	7 8½
9½	1 7	2 4½	3 2	3 11½	4 9	5 6½	6 4	7 1½	7 11
9¾	1 7½	2 5¼	3 3	4 0¾	4 10½	5 8¼	6 6	7 3¾	8 0½
10	1 8	2 6	3 4	4 2	5 0	5 10	6 8	7 6	8 4
10¼	1 8½	2 6¾	3 5	4 3¼	5 1½	5 11¾	6 10	7 8¼	8 6½
10½	1 9	2 7½	3 6	4 4½	5 3	6 1½	7 0	7 10½	8 9
10¾	1 9½	2 8¼	3 7	4 5¾	5 4½	6 3¼	7 2	8 0¾	8 11½
11	1 10	2 9	3 8	4 7	5 6	6 5	7 4	8 3	9 2
11¼	1 10½	2 9¾	3 9	4 8¼	5 7½	6 6¾	7 6	8 5¼	9 4½
11½	1 11	2 10½	3 10	4 9½	5 9	6 8½	7 8	8 7½	9 7
11¾	1 11½	2 11¼	3 11	4 10¾	5 10½	6 10¼	7 10	8 9¾	9 9½

Wages Table.

Wages Per Year.	= Approximately													
	Per Half Year.			Per Quarter Year.			Per Month.			Per Week.		Per Day.	
£	£.	s.	d.	£.	s.	d.	£.	s.	d.	s.	d.	s.	d.
1	0	10	0	0	5	0	0	1	8	0	4½	0	¾
2	1	0	0	0	10	0	0	3	4	0	9¼	0	1¼
3	1	10	0	0	15	0	0	5	0	1	1¾	0	2
4	2	0	0	1	0	0	0	6	8	1	6½	0	2¾
5	2	10	0	1	5	0	0	8	4	1	11	0	3¼
6	3	0	0	1	10	0	0	10	0	2	3¾	0	4
7	3	10	0	1	15	0	0	11	8	2	8¼	0	4½
8	4	0	0	2	0	0	0	13	4	3	1	0	5¼
9	4	10	0	2	5	0	0	15	0	3	5½	0	6
10	5	0	0	2	10	0	0	16	8	3	10¼	0	6½
11	5	10	0	2	15	0	0	18	4	4	2¾	0	7¼
12	6	0	0	3	0	0	1	0	0	4	7¼	0	8
13	6	10	0	3	5	0	1	1	8	5	0	0	8½
14	7	0	0	3	10	0	1	3	4	5	4½	0	9¼
15	7	10	0	3	15	0	1	5	0	5	9¼	0	9¾
16	8	0	0	4	0	0	1	6	8	6	1¾	0	10½
17	8	10	0	4	5	0	1	8	4	6	6½	0	11¼
18	9	0	0	4	10	0	1	10	0	6	11	0	11¾
19	9	10	0	4	15	0	1	11	8	7	3¾	1	0½
20	10	0	0	5	0	0	1	13	4	7	8¼	1	1¼
25	12	10	0	6	5	0	2	1	8	9	7¼	1	4½
30	15	0	0	7	10	0	2	10	0	11	6½	1	7¾
35	17	10	0	8	15	0	2	18	4	13	5½	1	11
40	20	0	0	10	0	0	3	6	8	15	4½	2	2¼
45	22	10	0	11	5	0	3	15	0	17	3¾	2	5½
50	25	0	0	12	10	0	4	3	4	19	2¾	2	9

English Coins.

A pound sterling consists of gold .. 113·001 grains.
" " copper .. 10·273 "
or a fineness of ·916⅔.
Total weight .. .. 123·274 "

1 shilling =87·273 grains. | 12 pence .. .. = ¼ lb. avoir.
20 shillings= 3·636 oz. troy. | Or pence in £ = 5 lbs. "

1 lb. troy (37 silver to 3 alloy) = 66*s*.

Copper Coinage.—A lb. avoir. of copper is coined into 48 pence or 96 halfpence.

Bronze Coinage.—95 copper, 4 tin, 1 zinc, is coined into 40 pence, 80 halfpence, 160 farthings.

Indian Weights and Measures.

North India. Length.

Jow.	Guj.	Kos.	English.
1	·00694	·0000017	—
144	1	·00025	33 ins.
576000	4000	1	2·08 miles.

North India. Square Measure

Guj.	Baus.	Biga.	English.
1	·111111	·00028	·84028 sq. yd.
9	1	·0025	7·5625 „ „
3600	400	1	·624 acres

The kos varies from 1 to 2 miles in North India; in the Punjab it is generally 2 miles. The English yard is frequently called a guj. A biga in Bengal = ·3306 acre.

North India. Weight.

Tola.	Chitak.	Seer.	Maund.	Lbs. avoir.
1	·2	·0125	·000313	·0257
5	1	·0625	·00156	·12857
80	16	1	·025	2·0571
3200	640	40	1	82·2857

North India. Capacity.

Seer.	Pali.	Maund.	Gallons.
1	·2	·025	·245
5	1	·125	1·226
40	8	1	9·81

Madras. Length.

Span.	Cubit.	Kos.	English.
1	·4444	·0000556	8 ins.
2¼	1	·000125	18 „
18000	8000	1	2·27 m.

Madras. Square Measure.

Kōl.	Gūli.	Kāni.	English.
1	·04167	·0004167	24 sq. ft.
24	1	·010	576 „ „
2400	100	1	1·32 acre.

Madras. Weight.

Tola.	Pollam.	Vis.	Maund.	Candy.	Lbs. avoir.
1	·333	·00833	·001042	·0000521	·0257
3	1	·025	·003125	·0001563	·07714
120	40	1	·125	·00625	3·0857
960	320	8	1	·05	24·686*
19200	6400	160	20	1	493·714*

* Frequently assumed at 25 and 500 lbs. respectively.

Madras. Capacity.

Olak.	Padi.	Mercal.	Para.	Gās.	English.
1	·08	·01	·002	·000025	8
12½	1	·125	·025	·0003175	100 cb. ins.
100	8	1	·2	·0025	800 „ „
500	40	5	1	·0125	4000 „ „
40000	3200	400	80	1	185·2 cb. ft.

Indian Weights and Measures—*continued.*

BOMBAY. LENGTH. BOMBAY. SQUARE MEASURE.

Tasū.	Hāth.	Guj.	Inches.	Kati.	Pand.	Biga.	English.
1	·0625	·04167	1·125	1	·05	·0025	10 sq. yds.
16	1	·6667	18	20	1	·05	200 " "
24	1·5	1	27	400	20	1	·825 acre.

BOMBAY. CAPACITY. BOMBAY. WEIGHT.

Seer.	Paili.	Para.	Candy.	Cub. In.	Gallons.	
1	·25	·015625	·00195	49	·18	1 seer = ·7 lb.
4	1	·0625	·00781	197	·71	1 maund = 28 lbs.
64	16	1	·125	3145	11·34	1 candy = 5 cwt.
512	128	8	1	25160	90·74	

Indian Money (par being 2*s.* = 1 rupee).

Pie.	Annas.	Rupees.	English at par.
1	·0833	·005208	·125 pence.
12	1	·0625	$1\frac{1}{2}$ "
192	16	1	2 shillings.

1 lakh = 1,00,000 rupees = £10,000. 1 crore = 1,00,00,000 rupees = £1,000,000. The "pice" = 3 "pie" or $\frac{1}{4}$ anna. In Ceylon the rupee is divided into 100 parts called "cents."

Multipliers for the Conversion of £ Sterling and Rupees.

V = Rate of exchange for the rupee in shillings and pence.

V	1 $11\frac{3}{4}$	1 $11\frac{1}{2}$	1 $11\frac{1}{4}$	1 11	1 $10\frac{3}{4}$	1 $10\frac{1}{2}$	1 $10\frac{1}{4}$	1 10	V
£ ×	10·1053	10·2127	10·3226	10·4348	10·5495	10·6667	10·7865	10·9091	= Rs.
Rs. ×	·098958	·097917	·096875	·095833	·094792	·093750	·092708	·091667	= £
V	1 $9\frac{3}{4}$	1 $9\frac{1}{2}$	1 $9\frac{1}{4}$	1 9	1 $8\frac{3}{4}$	1 $8\frac{1}{2}$	1 $8\frac{1}{4}$	1 8	V
£ ×	11·0345	11·1628	11·2941	11·4286	11·5663	11·7073	11·8519	12·0000	= Rs.
Rs. ×	·090625	·089583	·088542	·087500	·086458	·085417	·084375	·083333	= £
V	1 $7\frac{3}{4}$	1 $7\frac{1}{2}$	1 $7\frac{1}{4}$	1 7	1 $6\frac{3}{4}$	1 $6\frac{1}{2}$	1 $6\frac{1}{4}$	1 6	V
£ ×	12·1519	12·3077	12·4675	12·6316	12·8000	12·9730	13·1507	13·3333	= Rs.
Rs. ×	·082292	·081250	·080208	·079167	·078125	·077083	·076042	·075	= £

Table for the Conversion of Annas and Pie into Cents, or 100ths of a Rupee.

Pie.	Annas. 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Continuation of the Decimal.
0	00·00	06·25	12·50	18·75	25·00	31·25	37·50	43·75	50·00	56·25	62·50	68·75	75·00	81·25	87·50	93·75	0000
1	00·52	06·77	13·02	19·27	25·52	31·77	38·02	44·27	50·52	56·77	63·02	69·27	75·52	81·77	88·02	94·27	0833
2	01·04	07·29	13·54	19·79	26·04	32·29	38·54	44·79	51·04	57·29	63·54	69·79	76·04	82·29	88·54	94·79	1666
3	01·56	07·81	14·06	20·31	26·56	32·81	39·06	45·31	51·56	57·81	64·06	70·31	76·56	82·81	89·06	95·31	2500
4	02·08	08·33	14·58	20·83	27·08	33·33	39·58	45·83	52·08	58·33	64·58	70·83	77·08	83·33	89·58	95·83	3333
5	02·60	08·85	15·10	21·35	27·60	33·85	40·10	46·35	52·60	58·85	65·10	71·35	77·60	83·85	90·10	96·35	4166
6	03·12	09·37	15·62	21·87	28·12	34·37	40·62	46·87	53·12	59·37	65·62	71·87	78·12	84·37	90·62	96·87	5000
7	03·64	09·89	16·14	22·39	28·64	34·89	41·14	47·39	53·64	59·89	66·14	72·39	78·64	84·89	91·14	97·39	5833
8	04·16	10·41	16·66	22·91	29·16	35·41	41·66	47·91	54·16	60·41	66·66	72·91	79·16	85·41	91·66	97·91	6666
9	04·68	10·93	17·18	23·43	29·68	35·93	42·18	48·43	54·68	60·93	67·18	73·43	79·68	85·93	92·18	98·43	7500
10	05·20	11·45	17·70	23·95	30·20	36·45	42·70	48·95	55·20	61·45	67·70	73·95	80·20	86·45	92·70	98·95	8333
11	05·72	11·97	18·22	24·47	30·72	36·97	43·22	49·47	55·72	61·97	68·22	74·47	80·72	86·97	93·22	99·47	9166
Pie.	Annas. 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	

COMPARISON OF ENGLISH, FRENCH, AMERICAN, AND GERMAN COINS.

		English.	French.	American.	German.
Gold.	Denomination	Sovereign.	20 franc.	Eagle.	20 mark.
	Total weight, grains troy	123·27	99·56	258	122·918
	Fine *	916·67	900	899·3	900
	Weight of pure gold, gr. troy	113·0016	89·6	232	110·626
	Equiv.† to 1 sov., grs. troy	113·0016	112	111·36	110·626
	Ratio of silver to gold ..	14·6	15·5	16	13·95
Silver.	Equiv. to 1 sov., grs. troy	1650	1736·1	1782	1543
	Weight of pure silver, gr. troy	165	347·23	371·25	77·16
	Fine	916·67	900	900	900
	Total weight, grains troy	180	385·81	412·5	85·73
	Denomination	Rupee.	5 franc.	Dollar.	Mark.

The English florin = 175½ grains; or 161·45 pure silver = 920 fine.

ALTERED COINAGE, NECESSARY FOR INTERCHANGE UNDER A BI-METALLIC STANDARD.

		English.	French‡	American.	German.
Gold.	Denomination	Sovereign.	20 franc.	Eagle.	20 mark.
	Total weight, grains troy	124·45	99·56	259·26	144·45
	Fine *	900	900	900	900
	Weight of pure gold, gr. troy	112	89·6	233·3	112
	Equiv. to 1 sov., grs. troy	112	112	112	112
	Ratio of silver to gold ..	15·5	15·5	15·5	15·5
Silver.	Equiv. to 1 sov., grs. troy	1736·1	1736·1	1736·1	1736·1
	Weight of pure silver, gr. troy	173·6	347·2	361·7	86·8
	Fine	900	900	900	900
	Total weight, grains troy	192·9	385·81	401·9	96·5
	Denomination	Florin or Rupee.	5 franc.	Dollar.	Mark.

* The term Fine denotes the number of parts of pure metal in 1000, the remainder being alloy; thus 900 "fine" denotes 900 of pure metal to 100 of alloy.

† The equivalent is assumed at 25 francs, 4·8 dollars, 20 marks, 10 rupees.

‡ The French coinage is unaltered in this table.

Dollars and Cents.

The dollar is for rough approximations frequently assumed to be equal to 50 pence.

Dollars × ·20833 = £ sterling; £ × 4·8, or shillings × ·24 = dollars.

£	1	2	3	4	5	6	7	8	9	10
Dollars ..	4·8	9·6	14·4	19·2	24	28·8	33·6	38·4	43·2	48
Dollars ..	1	2	3	4	5	6	7	8	9	10
£	·208	·417	·625	·833	1·042	1·25	1·458	1·667	1·875	2·083
Dollars ..	1	2	3	4	5	6	7	8	9	10
Shillings	4/2	8/4	12/6	16/8	20/10	25/0	29/2	33/4	37/6	41/8

Cents compared with Shillings and Pence.

Cents.	Cents. 0		1		2		3		4		5		6		7		8		9		Cents.
	s.	d.	s.	d.	s.	d.	s.	d.	s.	d.	s.	d.	s.	d.	s.	d.	s.	d.	s.	d.	
0		0		½		1		1½		2		2½		3		3½		4		4½	0
10		5		5½		6		6½		7		7½		8		8½		9		9½	10
20		10		10½		11		11½	1	0	1	0½	1	1	1	1½	1	2	1	2½	20
30	1	3	1	3½	1	4	1	4½	1	5	1	5½	1	6	1	6½	1	7	1	7½	30
40	1	8	1	8½	1	9	1	9½	1	10	1	10½	1	11	1	11½	2	0	2	0½	40
50	2	1	2	1½	2	2	2	2½	2	3	2	3½	2	4	2	4½	2	5	2	5½	50
60	2	6	2	6½	2	7	2	7½	2	8	2	8½	2	9	2	9½	2	10	2	10½	60
70	2	11	2	11½	3	0	3	0½	3	1	3	1½	3	2	3	2½	3	3	3	3½	70
80	3	4	3	4½	3	5	3	5½	3	6	3	6½	3	7	3	7½	3	8	3	8½	80
90	3	9	3	9½	3	10	3	10½	3	11	3	11½	4	0	4	0½	4	1	4	1½	90
	0		1		2		3		4		5		6		7		8		9		

Foreign Weights and Measures.

The Metrical System has been adopted in France, Belgium, Netherlands, Switzerland, Germany, Italy, Spain, Portugal, Greece, Austria, Sweden, and Norway. Others will probably be added to the number. For detailed tables of Metric Values, see 'Molesworth's Metrical Tables,' which are uniform with and may be bound up with this Pocket-book.

RUSSIAN. WEIGHT.

Doli.	Zolotnik.	Funt.	Pood.	Lb. avoir.
1	—	—	—	—
96	1	—	—	—
9216	96	1	—	—
368640	3840	40	1	36·1141

RUSSIAN. DRY MEASURE.

Garnez.	Chetwerik.	Chetwert.	Gallons.
1	—	—	—
8	1	—	—
64	8	1	46·2

RUSSIAN. LENGTH.

Vershok.	Fuss.*	Sajen.	Verst.	English.
1	—	—	—	—
8	1	—	—	—
48	6	1	—	7 ft.
24000	3000	500	1	·663 m.

RUSSIAN. LIQUID MEASURE.

Stoof.	Vedro.	Oxhoft.	Gallons.
1	—	—	·2707
10	1	—	2·7069
—	18	1	48·725

* The English foot is now much used as the standard measure in Russia. Land is measured by the "Crown" dessatine of 2400 square sajen = 2·7 acres; common dessatine = 3·6 acres.

Turkey.

Weight 180 drakmas = 1 rotolo = 1·27 lb. avoir.
Liquid 1 almud = 1·1455 imp. gallon.
Dry 1 killow = ·97 ,, bushel.
Length 1 pik = 26·625 English inches.

Egypt.

Weight 144 drakmas = 1 rotolo = ·98046 lb. avoir.
Capacity 1 ardeb = 5·02 bushels.
Length 1 pik = 27 English inches.

China.

10,000 fun = 1000 tsun = 100 chih = 10 chang = 1 yin = 117½ ft. English.
100 koh = 10 shing = 1 tau = 1·13 gallon English.
1600 tael = 100 catty = 1 pecul = $132\frac{1}{8}$ lbs. avoir.

FOREIGN MONEY—SILVER COINS AND TOKENS.

Country.	Coin or Token.	Subdivisions.	Silver Value in Pence at 5s. per oz.	Total Weight Grs. Troy.	Fine.
England ..	Shilling	12 pence	10·09	87·270	925
America ..	Dollar	100 cents	46·40	412·49	900
Austria ..	Florin	100 kreuzer	21·43	190·512	900
Belgium ..	Franc	100 centime	8·05	77 162	835
Ceylon ..	Rupee	100 cents	20·625	180·000	916·67
Denmark ..	Krone	100 oere	11·57	115·743	800
Egypt ..	Piastre	100 aspre	2·17	19·290	900
France ..	Franc	100 centime	8·05	77·162	835
Germany ..	Mark	100 pfennig	9·64	85·727	900
Greece ..	Drachma	100 lepta	8·05	77·162	835
Holland ..	Guilder	100 cents	18·23	154·324	945
India ..	Rupee	192 pie	20·625	180·000	916·67
Italy ..	Lire	100 centesimi	8·05	77·162	835
Norway ..	Crown	100 oere	11·57	115·743	800
Portugal ..	Milrei	1000 reis	44·20	385·809	916·67
Russia ..	Rouble	100 kopeck	34·72	320·000	868
Spain ..	Peseta	100 centesimos	8·112	80·125	810
Sweden ..	Krona	100 oere	11·57	115·743	800
Switzerland	Franc	100 centime	8·05	77·162	835
Turkey ..	Piastre	100 aspre	1·93	18·565	830

METRICAL SYSTEM.

The English standard yard being of bronze at 62° Fahr., whilst the French standard mètre is of platinum at 0° C., the Standards Commission in the Report of 1871–72 considered a correction needed for scientific purposes to allow for this difference. In the Weights and Measures Act of 1878, however, the original equivalents as determined by Kater were adopted without the proposed correction. A comparison of the corrected and adopted equivalents is given below.

	Mètre.	Litre.	Kilogram.
	ins.	gall.	lbs.
Standards Commission ..	39·38203*	·22018†	2·20462
Adopted in Act 1878 ..	39·37079	·2200967	2·20462

* At equal temperatures in ordinary air.
At equal temperatures, distilled water.

Metrical Equivalents (Weights and Measures Act 1878).

		LINEAR MEASURES.	
		Mètres.	Reciprocals.
Inch	=	·02539954	39·37079
Foot	=	·3047945	3·280899
Yard	=	·91438348	1·093633
Pole	=	5·029109	·1988424
Chain	=	20·11644	·0497106
Furlong	=	201·1644	·004971
Mile	=	1609·3149	·00062138
		SQUARE MEASURES.	
		Square mètres.	Reciprocals.
Square inch	=	·000645137	1550·591
„ foot	=	·09289968	10·7643
„ yard	=	·836097	1·196033
Perch	=	25·29194	·0395383
Rood	=	1011·678	·00098846
Acre	=	4046·71	·00024711
Square mile	=	2589894·5	·00000038612
		CUBIC MEASURES.	
		Cubic mètres.	Reciprocals.
Cubic inch	=	·000016386	61027·05
„ foot	=	·0283153	35·31658
„ yard	=	·764513	1·30802
		MEASURES OF CAPACITY.	
		Litres.	Reciprocals.
Gill	=	·141983	7·043094
Pint	=	·56793	1·760773
Quart	=	1·13586	·8803868
Gallon	=	4·543457	·2200967
Peck	=	9·086915	·1100483
Bushel	=	36·34766	·027512
Quarter	=	290·7813	·003439
		WEIGHTS.	
		Grammes.	Reciprocals.
Drachm avoirdupois	=	1·771836	·564383
Ounce „	=	28·349375	·0352739
Pound „	=	453·59265	·00220462
Hundred-weight „	=	50802·38	·00001968
Ton „	=	1016047·5	·000000984
Grain Troy	=	·06479895	15·43235
Penny-weight „	=	1·555175	·6430146
Ounce „	=	31·1034615	·03215073
Pound „	=	373·2419	·00267923

INCHES AND 16THS CONVERTED INTO MILLIMETRES.

Ins.	0	1	2	3	4	5	6	7	8	9	10	11	Ins.
	..	25·400	50·799	76·199	101·60	127·00	152·40	177·80	203·20	228·60	254·00	279·39	
$\frac{1}{16}$	1·5875	26·987	52·387	77·786	103·19	128·59	153·98	179·38	204·78	230·18	255·58	280·98	$\frac{1}{16}$
$\frac{1}{8}$	3·1749	28·574	53·974	79·374	104·77	130·17	155·57	180·97	206·37	231·77	257·17	282·57	$\frac{1}{8}$
$\frac{3}{16}$	4·7624	30·162	55·561	80·961	106·36	131·76	157·16	182·56	207·96	233·36	258·76	284·16	$\frac{3}{16}$
$\frac{1}{4}$	6·3499	31·749	57·149	82·549	107·95	133·35	158·75	184·15	209·55	234·95	260·35	285·74	$\frac{1}{4}$
$\frac{5}{16}$	7·9374	33·337	58·736	84·136	109·54	134·94	160·33	185·73	211·13	236·53	261·93	287·33	$\frac{5}{16}$
$\frac{3}{8}$	9·5248	34·924	60·324	85·723	111·12	136·52	161·92	187·32	212·72	238·12	263·52	288·92	$\frac{3}{8}$
$\frac{7}{16}$	11·112	36·512	61·911	87·311	112·71	138·11	163·51	188·91	214·31	239·71	265·11	290·51	$\frac{7}{16}$
$\frac{1}{2}$	12·700	38·099	63·499	88·898	114·30	139·70	165·10	190·50	215·90	241·30	266·70	292·09	$\frac{1}{2}$
$\frac{9}{16}$	14·287	39·687	65·086	90·486	115·89	141·28	166·68	192·08	217·48	242·88	268·28	293·68	$\frac{9}{16}$
$\frac{5}{8}$	15·875	41·274	66·674	92·073	117·47	142·87	168·27	193·67	219·07	244·47	269·87	295·27	$\frac{5}{8}$
$\frac{11}{16}$	17·462	42·862	68·261	93·661	119·06	144·46	169·86	195·26	220·66	246·06	271·46	296·86	$\frac{11}{16}$
$\frac{3}{4}$	19·050	44·449	69·849	95·248	120·65	146·05	171·45	196·85	222·25	247·65	273·05	298·44	$\frac{3}{4}$
$\frac{13}{16}$	20·637	46·037	71·436	96·836	122·24	147·63	173·03	198·43	223·83	249·23	274·63	300·03	$\frac{13}{16}$
$\frac{7}{8}$	22·225	47·624	73·024	98·423	123·82	149·22	174·62	200·02	225·42	250·82	276·22	301·62	$\frac{7}{8}$
$\frac{15}{16}$	23·812	49·212	74·611	100·01	125·41	150·81	176·21	201·61	227·01	252·41	277·81	303·21	$\frac{15}{16}$
Ins.	0	1	2	3	4	5	6	7	8	9	10	11	Ins.

For mètres move the decimal point *three* figures forward.

Example.—$8\frac{3}{16}$ = 207·96 millimètres, = 20·796 centimètres, = 2·0796 decimètres, = ·20796 mètre

ALGEBRAIC SIGNS IN ORDINARY USE.

$+$	Plus, addition,
$+$	positive,
$+$	compression.
$-$	Minus, tension,
$-$	negative,
$-$	subtraction.
$=$	Equal to.
$\neq$	Unequal to.
$>$	Greater than.
$\ngtr$	Not greater than.
$<$	Less than.
$\nless$	Not less.
$\times$	Multiplied by.
$::$	Multiplied by.
$::$	Is to (ratio).
$:$	As; so is (ratio).
$\div$	Divided by.
$\perp$	Perpendicular to.
$\parallel$	Parallel to.
$\nparallel$	Not parallel.
$\because$	Because.
$\therefore$	Therefore.
$\angle$	Angle.
∟	Right angle.
$\triangle$	Triangle.
▭	Parallelogram.
□	Square.
○	Circumference.
⊙	Circle.
◓	Semicircle.
◔	Quadrant.
∞	Infinity.
⌒	Arc.
$\backsim$	Difference.

( ) [ ] { } ——— Vincula denoting that the numbers are to be taken together. *Example.*—

$5\,(a-b)$; or $5\,[a-b]$; or $5\,\overline{a-b}$; $=5\,a-5\,b$.

$a : b :: c : d = a$ is to b as c is to d.

$$\frac{a+b}{c-d} = (a+b) \div (c-d).$$

a', a'', a'''; or b', $b_{,,}$, $b_{,,,}$, accents denoting quantities of the same kind.

$45^\circ = 45$ degrees; $20' = 20$ minutes; $25'' = 25$ seconds; $12''' = 12$ thirds.

The first letters of the alphabet, a, b, c, &c., are often used to denote known quantities, whilst the last, x, y, z, to denote unknown quantities. The following letters are frequently used as follows:–

c	Constant.	α	An angle.
d	Differential (see Calculus).	δ	Variation.
E	Modulus of elasticity.	Δ	Finite difference.
$\int$	Integration (see Calculus).	ϵ	Base of hyperbolic logarithms.
F or f	Functions.	θ, ϕ	Any angles.
g	Gravity $= 32 \cdot 2$.	λ	Latitude.
k	Coefficient.	π	Ratio of circumference to diameter $= 3 \cdot 14159$.
M	Modulus.	ρ	Radius.
n	Any number.	Σ	Sum of finite quantities.
R°	Radius in degrees of arc $= 57^\circ \cdot 2958$.		
R′	Do. minutes $= 3437' \cdot 75$.		

$\sqrt{\ }$ Square root.	$a^2 = a$ squared.
$\sqrt[3]{\ }$ Cube root.	$a^3 = a$ cubed.
$\sqrt[n]{\ }$ n^{th} root.	$a^n = a$ raised to the power of a number equal n.
Sin. $a =$ the sine of a.	$a^{\frac{2}{3}} = \sqrt[3]{a^2}$.
Sin.$^{-1}$ $a =$ the arc whose sine is a.	
$(\text{Sin.}\,a)^{-1} = \dfrac{1}{\sin . a}$.	

ALGEBRAIC FORMULÆ (from 'Algebra Self-taught,' Dr. Paget Higgs).

ADDITION AND SUBTRACTION. $n + (-m) = n - m = -(m - n)$; $n - (+m) = n + (-m)$; $n - (-m) = n + (+m) = n + m$.

MULTIPLICATION. $a . b = a \times b = ab$; $n(m + p) = nm + np$; $(-n) \times (-m) = +mn$; $(+n)(-m) = -mn$.

DIVISION. $a \div b = \frac{a}{b} = a : b$; $(-a):(-b) = a : b = +\frac{a}{b}$;

$(-a):(+b) = (+a):(-b) = -\frac{a}{b}$; $\frac{m \pm n}{p} = \frac{m}{p} \pm \frac{n}{p}$;

$\frac{mn}{p} = \frac{m}{p} . n = m . \frac{n}{p}$; $\frac{p}{mn} = \frac{p}{m} : n = \frac{p}{n} : m$.

FRACTIONS. $\frac{a}{b} = \frac{an}{bn} = \frac{a:n}{b:n}$; $\frac{a}{b} \pm \frac{n}{b} = \frac{a \pm n}{b}$;

$\frac{a}{b} . \frac{n}{p} = \frac{an}{bp}$; $\frac{a}{b} : \frac{n}{p} = \frac{a}{b} . \frac{p}{n} = \frac{ap}{bn}$.

POWERS AND ROOTS. $a^m . b^m = (ab)^m$; $a^m : b^m = \left(\frac{a}{b}\right)^m$;

$a^m . a^n = a^{m+n}$; $a^m : a^n = a^{m-n}$; $(a^m)^n = a^{mn}$;
$(-a)^{2n} = a^{2n}$; $(-a)^{2n+1} = -a^{2n+1}$; $(a \pm b)^2 = a^2 \pm 2ab + b^2$;
$(a \pm b)^3 = a^3 \pm 3a^2b + 3ab^2 \pm b^3$; $n^0 = 1$; $a^{-\infty} =$ either 0 or ∞;

$x^{-m} = \frac{1}{x^m}$; $x^m = \frac{1}{x^{-m}}$; $a^{\frac{1}{m}} = \sqrt[m]{a}$; $a^m = \sqrt[\frac{1}{m}]{a}$;

$\sqrt[m]{a} . \sqrt[m]{b} = \sqrt[m]{ab}$; $\sqrt[n]{a} : \sqrt[n]{b} = \sqrt[n]{\frac{a}{b}}$; $\sqrt[m]{a^n} = (\sqrt[m]{a})^n$;

$\sqrt[n]{\sqrt[m]{a}} = \sqrt[m]{\sqrt[n]{a}}$; $\sqrt[m]{\sqrt[n]{a}} = \sqrt[mn]{a}$; $\sqrt[2m]{+a} = \pm b$;
$\sqrt[2m]{-a} = \pm b\sqrt{-1}$; $\sqrt[2m+1]{+a} = +c$; $\sqrt[2m+1]{-a} = -c$.

LOGARITHMS. $\log . mn = \log . m + \log . n$; $\log . \frac{m}{n} = \log . m - \log . n$;

$\log . x^m = m \log . x$; $\log . \sqrt[m]{x} = \frac{\log . x}{m}$.

EQUATIONS. Let $x \pm m = n$, then $x = n \mp m$. Let $nx = m$, then $x = \frac{m}{n}$.

Let $\frac{x}{n} = m$, then $x = nm$. Let $\frac{n}{x} = m$, then $x = \frac{n}{m}$.
Let $x^n = m$, then $x = \sqrt[n]{m}$. Let $\sqrt[n]{x} = m$, then $x = m^n$.
Let $a^x = b$, then $x \log . a = \log . b$, and $x = \frac{\log . b}{\log . a}$.

ALGEBRAIC FORMULÆ—*continued.*

EQUATIONS. $x : n = m : p$; then $x p = m n$;

$x : n = m : x$, or $n : x = x : m$, then $x^2 = m n$, and $x = \sqrt{m n}$;

$x : n = m : p$, then $x : m = n : p$, and $(x \pm n) : n = (m \pm p) : p$.

QUADRATIC EQUATIONS. $x^2 + a x = b$, then $x = -\frac{a}{2} \pm \sqrt{b + \left(\frac{a}{2}\right)^2}$;

$$x^{2n} + a x^n = b, \text{ then } x = \sqrt[n]{-\frac{a}{2} \pm \sqrt{b + \left(\frac{a}{2}\right)^2}};$$

$$x + y = s, \text{ and } x y = p, \text{ then } x = \frac{s + \sqrt{s^2 - 4p}}{2}, \text{ and } y = \frac{s - \sqrt{s^2 - 4p}}{2}.$$

CUBIC EQUATION. $x^3 + ax^2 + bx + c = 0$, becomes $x^3{}_1 + b_1 x_1 + c_1 = 0$, if we put $x_1 = x - \frac{a}{3}$; $b_1 = b - \frac{a^2}{3}$; and $c_1 = c - \frac{a b}{3} + \frac{2}{27} a^3$.

Cardan's solution of $x^3 + b x + c = 0$ is as follows:—

$$x = \sqrt[3]{-\frac{c}{2} + \sqrt{\left(\frac{b}{3}\right)^3 + \left(\frac{c}{2}\right)^2}} + \sqrt[3]{-\frac{c}{2} - \sqrt{\left(\frac{b}{3}\right)^3 + \left(\frac{c}{2}\right)^2}}.$$

This rule is correct if b is positive; or if b is negative and $\left(\frac{b}{3}\right)^3 > \left(\frac{c}{2}\right)^2$.

If b is negative and $\left(\frac{b}{3}\right)^3 = \left(\frac{c}{2}\right)^2$, the equation has three true roots—

$$x = -2\sqrt[3]{\frac{c}{2}}, \quad x = \sqrt[3]{\frac{c}{2}}, \quad x = \sqrt[3]{\frac{c}{2}}.$$

If b is negative and $\left(\frac{b}{3}\right)^3 > \left(\frac{c}{2}\right)^2$, the roots are real but imaginary.

APPROXIMATION FORMULÆ. If x_1 approximates to $x^2 + a x + b = 0$, then x (nearly) $= \frac{x_1{}^2 - b}{2 x_1 + a}$.

If x_1 approximates to $x^3 + a x^2 + b x + c = 0$, then

$$x = \frac{2 x_1{}^3 + a x_1{}^2 - c}{3 x_1{}^2 + 2 a x_1 + b}.$$

If x_1 approximates to $x^4 + a x^3 + b x^2 + c x + d = 0$, then

$$x = \frac{3 x_1{}^4 + 2 a x_1{}^3 + b x_1{}^2 - d}{4 x_1{}^3 + 3 a x_1{}^2 + 2 b x_1 + c}.$$

ERRORS OF OBSERVATION. (Paget Higgs.)

Let n = number of observations;

" $d_1\ d_2\ d_3\ .\ .\ .\ d_n$ = differences from the arithmetical mean;

" S = the sum of the squares of the errors, i. e.

$$S = d_1^2 + d_2^2 + d_3^2 + \ .\ .\ .\ .\ .\ d_n^2.$$

Then, the mean error of a *single* observation

$$= \pm\sqrt{\frac{S}{n-1}}.$$

" the mean error of the *result* $= \pm\sqrt{\frac{S}{n(n-1)}}$.

" the probable error of a single observation

$$= \pm\, 0\cdot6745 \times \sqrt{\frac{S}{n-1}}.$$

" the probable error of the result $= \pm\, 0\cdot6745$

$$\times \sqrt{\frac{S}{n(n-1)}}.$$

$0\cdot6745 = \frac{2}{3}$, for all practical purposes.

The probable error means that it is as likely that the actual unknown error is less than the probable error as that it is greater.

Interest (Simple and Compound), Annuities, &c.

P = Principal in £ sterling.
n = Number of years, integral or fractional.
R = Amount of £1 at given rate per cent.
r = Interest " " "
I = Interest; M = Amount; D = Discount; W = Present worth.
A = Annuity to continue for n years.
V = Present value of an annuity.

Simple Interest, $I = P n r$; $M = P(1 + nr)$;

$$W = \frac{P}{1 + nr}; \; D = P - W = \frac{P n r}{1 + nr}.$$

Compound Interest, $M = P R^n$.

Annuities (Simple Interest), $M = n A \left(1 + \frac{n-1}{2} r\right)$;

$$V = \frac{n A \left(1 + \frac{n-1}{2} r\right)}{1 + nr}.$$

Annuities (Compound Interest), $M = \frac{R^n - 1}{R - 1} A$;

$$V = \frac{R^n - 1}{R^n (R - 1)} A.$$

Duration, or First Cost.

y = First cost of less durable article.
x = First cost of more durable article to be on an equality with y.
N = Number of years' duration of x.
n = Number of years' duration of y.
i = Rate of interest per annum in decimals of 100; for example, 5 per cent. = ·05.

$$x = y \frac{(1 + i)^N - 1}{(1 + i)^N - (1 + i)^{N-n}}.$$

Value of x at different rates of interest ($y = 1$).

Duration, Years.		x at Rates of Interest per Cent. per Annum.			
n	N	3	4	5	6
2	10	4·4604	4·3029	4·1539	4·0142
5	20	3·2491	3·0541	2·8783	2·7231
10	50	3·0162	2·6485	2·3644	2·1416
20	100	2·1237	1·8031	1·5926	1·4487

Interpolation (Sum and Difference), &c.

A = Any term of an equidistant series of terms.
a, b, c, &c. = The *first* term of the 1st, 2nd, 3rd, &c., orders of differences.
z = The term required.
x = The distance of z from A.

$$z = A + xa + x\frac{x-1}{2}b + x\frac{x-1}{2}\cdot\frac{x-2}{3}c, \text{ \&c.}$$

Example.—Find the 30th term of a series of 1, 8, 27, 64, 125, &c.

1 = A				
	7 = a			
8		12 = b		
	19		6 = c	
27		18		0 = d
	37		6	
64		24		
	61			
125				

Then x being = 29; A = 1; a = 7; b = 12; and c = 6,

$$z = 1 + (29\times 7) + \left(29\times\frac{28}{2}\times 12\right) + \left(29\times\frac{28}{2}\times\frac{27}{3}\times 6\right) = 27000.$$

For Interpolating a Term in a Series.

a, b, c, d, &c. = A series of equidistant terms.
n = The number of terms whose value is given. Then the required term will be found by reducing the equation that corresponds with n.

$a - b = 0$	equation	when	$n = 1$
$a - 2b + c = 0$	"	"	$= 2$
$a - 3b + 3c - d = 0$	"	"	$= 3$
$a - 4b + 6c - 4d + e = 0$	"	"	$= 4$
$a - 5b + 10c - 10d + 5e - f = 0$	"	"	$= 5$
$a - nb + n\frac{n-1}{2}c - n\frac{n-1}{2}\cdot\frac{n-2}{3}d$, &c.,			$n = n$

Example.—Given a, b, d, e, to find c; then as $n = 4$, by reducing the equation $n = 4$, $c = \dfrac{4(b+d)-(a+e)}{6}$.

$$\left.\begin{array}{ll}\text{Given} & \log. 2523 = 4019173 = b\\ \quad " & \log. 2525 = 4022614 = d\end{array}\right\} 4(b+d) = 32167148$$

$$\left.\begin{array}{ll}\quad " & \log. 2522 = 4017451 = a\\ \quad " & \log. 2526 = 4024333 = e\end{array}\right\} (a+e) = 8041784$$

$$4(b+d) - (a+e) = 24125364$$

Required log. 2524 = 24125364 ÷ 6 = 4020894.

Conversion of Rates (Multiplier = x).

$x = m\,N = N \div M$; where M and N = the number of times the *given* rates are contained in the *required* rates; and m and n the times the *required* rates are contained in the *given* rates respectively; for M per N, or m per n.

Arithmetical and Geometrical Progression

A = First term.
x = Any term whose number is n from A.
n = Number of terms between A and x.
S = Sum of all the terms.
D = Difference between the terms.
R = Ratio by which the terms are to be multiplied or divided.

ARITHMETICAL PROGRESSION.

$$A = x - D(n-1) \quad = \frac{2S}{n} - x.$$

$$x = A + D(n-1) \quad = \frac{2S}{n} - A.$$

$$n = \frac{x - A}{D} + 1.$$

$$D = \frac{x - A}{n - 1}.$$

$$S = \frac{1}{2} n (A + x).$$

GEOMETRICAL PROGRESSION.

$$A = \frac{x}{R^{n-1}} \quad = S - R(S - x).$$

$$x = A R^{n-1} \quad = S - \frac{S - A}{R}.$$

$$R = \sqrt[n-1]{\frac{x}{A}}.$$

$$S = \frac{Rx - A}{R - 1}$$

TRIGONOMETRY.

SUPPLEMENT OF AN ANGLE.

The supplement of an angle A = 180° − A.

Sin. (180 − A) = Sin. A.
Cosin. (180 − A) = − Cosin. A.
Tan. (180 − A) = − Tan. A.
Cotan. (180 − A) = − Cotan. A.
Secant (180 − A) = − Secant A.
Cosecant (180 − A) = Cosecant A.
Versin. (180 − A) = 2 − Versin. A.
Coversin. (180 − A) = Coversin. A.

VALUES OF THE TRIGONOMETRICAL RATIOS.

For the more common angles, ∞ denotes infinity.

Angle ..	0°	30°	45°	60°	90°	120°	135°	150°	180°
Sine	0	$\frac{1}{2}$	$\frac{1}{\sqrt{2}}$	$\frac{\sqrt{3}}{2}$	1	$\frac{\sqrt{3}}{2}$	$\frac{1}{\sqrt{2}}$	$\frac{1}{2}$	0
Cosine ..	1	$\frac{\sqrt{3}}{2}$	$\frac{1}{\sqrt{2}}$	$\frac{1}{2}$	0	$-\frac{1}{2}$	$-\frac{1}{\sqrt{2}}$	$-\frac{\sqrt{3}}{2}$	−1
Tangent ..	0	$\frac{1}{\sqrt{3}}$	1	$\sqrt{3}$	∞	$-\sqrt{3}$	−1	$-\frac{1}{\sqrt{3}}$	0
Cotangent..	∞	$\sqrt{3}$	1	$\frac{1}{\sqrt{3}}$	0	$-\frac{1}{\sqrt{3}}$	−1	$-\sqrt{3}$	∞
Secant ..	1	$\frac{2}{\sqrt{3}}$	$\sqrt{2}$	2	∞	−2	$-\sqrt{2}$	$-\frac{2}{\sqrt{3}}$	−1
Cosecant ..	∞	2	$\sqrt{2}$	$\frac{2}{\sqrt{3}}$	1	$\frac{2}{\sqrt{3}}$	$\sqrt{2}$	2	∞
Versed sine	0	$\frac{2-\sqrt{3}}{2}$	$\frac{\sqrt{2}-1}{\sqrt{2}}$	$\frac{1}{2}$	1	$\frac{3}{2}$	$\frac{\sqrt{2}+1}{\sqrt{2}}$	$\frac{2+\sqrt{3}}{2}$	2

TRIGONOMETRICAL EQUIVALENTS.

$\frac{\text{Sin. }\theta}{\text{Cos. }\theta} = \text{tan. }\theta$; $\frac{\text{Cos. }\theta}{\text{Sin. }\theta} = \text{cotan. }\theta$;

$\text{Sin.}^2\,\theta + \text{cos.}^2\,\theta = 1$; Secant $\theta \times$ cosin. $\theta = 1$;

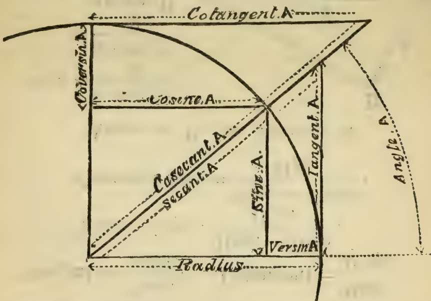
Tan. $\theta \times$ cotan. $\theta = 1$; $1 + \text{tan.}^2\,\theta = \text{sec.}^2\,\theta$

Sin. $\theta \times$ cosec. $\theta = 1$; Versin. $\theta = 1 -$ cosin. θ;

$1 + \text{cotan.}^2\,\theta = \text{cosec.}^2\,\theta$; Coversin. $\theta = 1 -$ sin. θ.

TRIGONOMETRICAL EXPRESSIONS.

The diagram shows the different trigonometrical functions in terms of the angle A to the radius = 1.



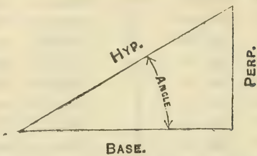
Complement of an angle = its difference from 90
Supplement " " = " " 180°

TRIGONOMETRICAL EQUIVALENTS.

$\sqrt{(1 - \sin.^2)} = \cos.$	$\sqrt{(1 - \cos.^2)} = \sin.$
Sin. ÷ tan. = cos.	1 ÷ cot. = tan.
Sin. × cot. = cos.	1 ÷ sin. = cosec
Sin. ÷ cos. = tan.	1 ÷ cos. = sec.
Cos. ÷ sin. = cot.	1 ÷ cosec. = sin.
Cos. ÷ cot. = sin.	1 ÷ sec. = cos.
Tan. ÷ sin. = sec.	1 ÷ tan. = cot.
Tan. ÷ sec. = sin.	1 − cos. = versin.
Tan. × cot. = rad.	1 − sin. = coversin.

See Table of logarithmic sines, tangents, &c.
See Table of decimal equivalents of a degree.

TRIGONOMETRICAL FUNCTIONS.



$$\text{Sine} = \frac{\text{Perp.}}{\text{Hyp.}}; \qquad \text{Cosine} = \frac{\text{Base}}{\text{Hyp.}};$$

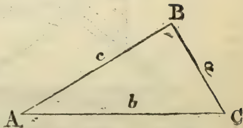
$$\text{Secant} = \frac{\text{Hyp.}}{\text{Base}}; \qquad \text{Cosecant} = \frac{\text{Hyp.}}{\text{Perp.}};$$

$$\text{Tangent} = \frac{\text{Perp.}}{\text{Base}}; \qquad \text{Cotangent} = \frac{\text{Base}}{\text{Perp.}}$$

$$\text{Versed sine} = \frac{\text{Hyp.} - \text{Base}}{\text{Hyp.}};$$

$$\text{Coversed sine} = \frac{\text{Hyp.} - \text{Perp.}}{\text{Hyp.}}.$$

AREAS OF PLANE TRIANGLES.

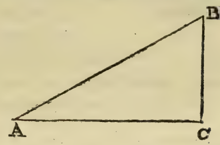


$$\text{Area} = \frac{b\,c \sin.\ A}{2} = \frac{a\,b \sin.\ C}{2} = \frac{c\,a \sin.\ B}{2}.$$

$$S = \tfrac{1}{2} \text{ sum of the sides} = \frac{a + b + c}{2}.$$

$$\text{Area} = \sqrt{S\,(S - a)\,(S - b)\,(S - c)},$$

Right-angled Triangles.



Let A B = Hypothenuse.
A C = Base.
B C = Perpendicular.
And A, B, and C the respective angles.

$$\text{Hypoth.} = \sqrt{\text{Base}^2 + \text{Perp.}^2}$$

$$\text{Base} = \sqrt{\text{Hyp.}^2 - \text{Perp.}^2}$$

$$\text{Perp.} = \sqrt{\text{Hyp.}^2 - \text{Base}^2}$$

$$\text{Sin. } A = \frac{BC}{AB}. \qquad \text{Cosin. } A = \frac{AC}{AB}.$$

$$\text{Tan. } A = \frac{BC}{AC}. \qquad \text{Cotan. } A = \frac{AC}{BC}.$$

$$\text{Secant } A = \frac{AB}{AC}. \qquad \text{Cosecant } A = \frac{AB}{BC}.$$

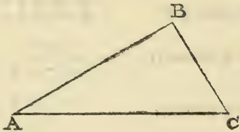
$$\text{Versin. } A = \frac{AB - AC}{AB}. \qquad \text{Coversin. } A = \frac{AB - BC}{AB}.$$

$BC = AB \cos. B.$ $\qquad AB = BC \sec. B.$
$AC = AB \sin. B.$

$B = \text{complement of } A = 90° - A.$

$A + B + C = 180°.$

Plane Triangles.



Value of any side A B; A, B, and C being the angles.

$$A\,B = \frac{B\,C \sin. C}{\sin. A} = \frac{A\,C \sin. C}{\sin. B}.$$

$$A\,B = \frac{B\,C}{\text{cosin. } B + \sin. B \text{ cotan. } C}.$$

$$A\,B = \frac{A\,C}{\text{cosin. } A + \sin. A \text{ cotan. } C}.$$

$$A\,B = B\,C \text{ cosin. } B + B\,C \sin. B \cot. A.$$

$$A\,B = A\,C \text{ cosin. } A + A\,C \sin. A \text{ cotan. } B.$$

$$A\,B = \sqrt{B\,C^2 + A\,C^2 - 2\,B\,C \times A\,C \cos. C}.$$

Value of any Angle A.

$$\text{Sin. } A = \frac{B\,C \sin. C}{A\,B} = \frac{B\,C \sin. B}{A\,C} = \sin. (B + C).$$

$$\text{Sin. } A = \sin. B \cos. C + \text{cosin. } B \sin. C.$$

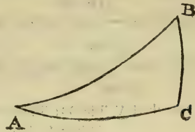
$$\text{Cosin. } A = \sin. B \sin. C - \text{cosin. } B \text{ cosin. } C = -\cos. (B + C).$$

$$\text{Cos. } A = \frac{A\,B^2 + A\,C^2 - B\,C^2}{2\,A\,B \times A\,C}.$$

$$\text{Tan. } A = \frac{B\,C \sin. C}{A\,C - B\,C \cos. C} = \frac{B\,C \sin. B}{A\,B - B\,C \cos. B}.$$

$$\text{Tan. } A = \frac{\tan. B + \tan. C}{\tan. B \tan. C - 1}.$$

Spherical Right-angled Triangles.

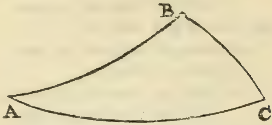


Right-angled Spherical Triangles.

Let A B be the Hypothenuse.
A C „ Base.
B C „ Perpendicular.
And A, B, and C the respective angles.

Sin. A = sin. B C cosect. A B
= sin. B C ÷ sin. A B.
Cosin. A = sin. B cosin. B C
= tan. A C cotan. A B.
Cotan. A = sin. A C cot. B C.
Sin. B = cosin. A secant B C.
Sin. A B = sin. B C cosect. A
= sin. B C ÷ sin. A.
Sin. A C = cotan. A tan. B C.
Sin. B C = sin. A sin. A B.
Cosin. A B = cosin. B C cosin. A C
= cotan. A cotan. B.
Cosin. A C = cosin. A B secant B C
= cosin. A B ÷ cosin. B C.
Cosin. B C = cosin. A cosect. B
= cosin. A ÷ sin. B.
Cotan. A B = cotan. A C cosin. A.

Oblique-angled Spherical Triangles.



$$\text{Sin. A} = \frac{\text{sin. B C sin. C}}{\text{sin. A B}} = \frac{\text{sin. B C sin. B}}{\text{sin. A C}}.$$

$$\text{Sin. B} = \frac{\text{sin. A C sin. A}}{\text{sin. B C}} = \frac{\text{sin. A C sin. C}}{\text{sin. A B}}.$$

$$\text{Sin. C} = \frac{\text{sin. A B sin. B}}{\text{sin. A C}} = \frac{\text{sin. A B sin. A}}{\text{sin. B C}}.$$

$$\text{Sin. A B} = \frac{\text{sin. A C sin. C}}{\text{sin. B}} = \frac{\text{sin. B C sin. C}}{\text{sin. A}}.$$

$$\text{Sin. A C} = \frac{\text{sin. B B sin. A}}{\text{sin. C}} = \frac{\text{sin. A B sin. B}}{\text{sin. C}}.$$

$$\text{Sin. B C} = \frac{\text{sin. A B sin. A}}{\text{sin. C}} = \frac{\text{sin. A C sin. A}}{\text{sin. B}}.$$

$$\text{Cosin. A} = \frac{\text{cos. B C} - \text{cos. A B cos. A C}}{\text{sin. A B sin. A C}}$$

$$= \text{cos. B C sin. B sin. C} - \text{cos. B cos. C}$$

$$\text{Cosin. A C} = \frac{\text{cos. B} + \text{cos. A cos. C}}{\text{sin. A sin. C}}$$

$$= \text{cos. B sin. B C sin. A B} + \text{cos. B C cos. A B.}$$

$$\text{Tan. A} = \frac{\text{sin. B}}{\text{sin. A B cot. B C} - \text{cosin. A B cosin. B}}$$

$$= \frac{\text{sin. C}}{\text{sin. A C cot. B C} - \text{cos. A C cos. C}}.$$

$$\text{Tan. A C} = \frac{\text{sin. B C}}{\text{sin. C cot. B} + \text{cos. C cos. B C}}$$

$$= \frac{\text{sin. B C}}{\text{sin. C cot. B} + \text{cos. C cos. B C}}.$$

NATURAL SINES, &c.

Deg.	Sine.	Cover.	Cosec.	Tan.	Cotan.	Secant.	Vrsn.	Cosin.	
0	·00	1·00000	Infinite.	·0	Infinite.	1·00000	·0	1·00000	90
1	·01745	·98255	57·2987	·01746	57·2900	1·00015	·00015	·99985	89
2	·03490	·96510	28·6537	·03492	28·6363	1·00061	·00061	·99939	88
3	·05234	·94766	19·1073	·05241	19·0811	1·00137	·00137	·99863	87
4	·06976	·93024	14·3356	·06993	14·3007	1·00244	·00244	·99756	86
5	·08716	·91284	11·4737	·08749	11·4301	1·00382	·00381	·99619	85
6	·10453	·89547	9·5668	·10510	9·5144	1·00551	·00548	·99452	84
7	·12187	·87813	8·2055	·12278	8·1443	1·00751	·00745	·99255	83
8	·13917	·86083	7·1853	·14054	7·1154	1·00983	·00973	·99027	82
9	·15643	·84357	6·3925	·15838	6·3138	1·01247	·01231	·98769	81
10	·17365	·82635	5·7588	·17633	5·6713	1·01543	·01519	·98481	80
11	·19081	·80919	5·2408	·19438	5·1446	1·01872	·01837	·98163	79
12	·20791	·79209	4·8097	·21256	4·7046	1·02234	·02185	·97815	78
13	·22495	·77505	4·4454	·23087	4·3315	1·02630	·02563	·97437	77
14	·24192	·75808	4·1336	·24933	4·0108	1·03061	·02970	·97030	76
15	·25882	·74118	3·8637	·26795	3·7321	1·03528	·03407	·96593	75
16	·27564	·72436	3·6280	·28675	3·4874	1·04030	·03874	·96126	74
17	·29237	·70763	3·4203	·30573	3·2709	1·04569	·04370	·95630	73
18	·30902	·69098	3·2361	·32492	3·0777	1·05146	·04894	·95106	72
19	·32557	·67443	3·0716	·34433	2·9042	1·05762	·05448	·94552	71
20	·34202	·65798	2·9238	·36397	2·7475	1·06418	·06031	·93969	70
21	·35837	·64163	2·7904	·38386	2·6051	1·07115	·06642	·93358	69
22	·37461	·62539	2·6695	·40403	2·4751	1·07853	·07282	·92718	68
23	·39073	·60927	2·5593	·42447	2·3559	1·08636	·07950	·92050	67
24	·40674	·59326	2·4586	·44523	2·2460	1·09464	·08645	·91355	66
25	·42262	·57738	2·3662	·46631	2·1445	1·10338	·09369	·90631	65
26	·43837	·56163	2·2812	·48773	2·0503	1·11260	·10121	·89879	64
27	·45399	·54601	2·2027	·50953	1·9626	1·12233	·10899	·89101	63
28	·46947	·53053	2·1301	·53171	1·8807	1·13257	·11705	·88295	62
29	·48481	·51519	2·0627	·55431	1·8040	1·14335	·12538	·87462	61
30	·50000	·50000	2·0000	·57735	1·7321	1·15470	·13397	·86603	60
31	·51504	·48496	1·9416	·60086	1·6643	1·16663	·14283	·85717	59
32	·52992	·47008	1·8871	·62487	1·6003	1·17918	·15195	·84805	58
33	·54464	·45536	1·8361	·64941	1·5399	1·19236	·16133	·83867	57
34	·55919	·44081	1·7883	·67451	1·4826	1·20622	·17096	·82904	56
35	·57358	·42642	1·7434	·70021	1·4281	1·22077	·18085	·81915	55
36	·58779	·41221	1·7013	·72654	1·3764	1·23607	·19098	·80902	54
37	·60182	·39819	1·6616	·75355	1·3270	1·25214	·20136	·79864	53
38	·61566	·38434	1·6243	·78129	1·2799	1·26902	·21199	·78801	52
39	·62932	·37068	1·5890	·80978	1·2349	1·28676	·22285	·77715	51
40	·64279	·35721	1·5557	·83910	1·1918	1·30541	·23396	·76604	50
41	·65606	·34394	1·5243	·86929	1·1504	1·32501	·24529	·75471	49
42	·66913	·33087	1·4945	·90040	1·1106	1·34563	·25686	·74314	48
43	·68200	·31800	1·4663	·93252	1·0724	1·36733	·26865	·73135	47
44	·69466	·30534	1·4396	·96569	1·0355	1·39016	·28066	·71934	46
45	·70711	·29289	1·4142	1·00000	1·0000	1·41421	·29289	·70711	45
	Cosin.	Versin.	Secant.	Cotan.	Tan.	Cosec.	Covn.	Sine.	Deg.

Points of the Compass and their corresponding Angles with the Meridian.

Points.	Angle. °	′	″	North.		South.	
¼	2	48	45				
½	5	37	30				
¾	8	26	15				
1	11	15	0	N. by E.	N. by W.	S. by E.	S. by W.
1¼	14	3	45				
1½	16	52	30				
1¾	19	41	15				
2	22	30	0	N.N.E.	N.N.W.	S.S.E.	S.S.W.
2¼	25	18	45				
2½	28	7	30				
2¾	30	56	15				
3	33	45	0	N.E. by N.	N.W. by N.	S.E. by S.	S.W. by S.
3¼	36	33	45				
3½	39	22	30				
3¾	42	11	15				
4	45	0	0	N.E.	N.W.	S.E.	S.W.
4¼	47	48	45				
4½	50	37	30				
4¾	53	26	15				
5	56	15	0	N.E. by E.	N.W. by W.	S.E. by E.	S.W. by W.
5¼	59	3	45				
5½	61	52	30				
5¾	64	41	15				
6	67	30	0	E.N.E.	W.N.W.	E.S.E.	W.S.W.
6¼	70	18	45				
6½	73	7	30				
6¾	75	56	15				
7	78	45	0	E. by N.	W. by N.	E. by S.	W. by S.
7¼	81	33	45				
7½	84	22	30				
7¾	87	11	15				
8	90	0	0	E.	W.	E.	W.

Decimal Equivalents of a Degree.
(Communicated by J. Gallott, Esq.)

Min.	0″	10″	20″	30″	40″	50″	Min.
0	·00000	·00278	·00556	·00833	·01111	·01389	0
1	·01667	·01944	·02222	·025	·02778	·03055	1
2	·03333	·03611	·03888	·04166	·04444	·04722	2
3	·05	·05278	·05555	·05833	·06111	·06388	3
4	·06666	·06944	·07222	·075	·07777	·08055	4
5	·08333	·08611	·08888	·09166	·09444	·09722	5
6	·1	·10277	·10555	·10833	·11111	·11388	6
7	·11667	·11944	·12222	·125	·12777	·13055	7
8	·13333	·13611	·13888	·14166	·14444	·14722	8
9	·15	·15277	·15555	·15833	·16111	·16388	9
10	·16666	·16944	·17222	·175	·17777	·18055	10
11	·18333	·18611	·18888	·19166	·19444	·19722	11
12	·2	·20277	·20555	·20833	·21111	·21388	12
13	·21666	·21944	·22222	·225	·22777	·23055	13
14	·23333	·23611	·23888	·24166	·24444	·24722	14
15	·25	·25277	·25555	·25833	·26111	·26388	15
16	·26666	·26944	·27222	·275	·27777	·28055	16
17	·28333	·28611	·28888	·29166	·29444	·29722	17
18	·3	·30277	·30555	·30833	·31111	·31388	18
19	·31666	·31944	·32222	·325	·32777	·33055	19
20	·33333	·33611	·33888	·34166	·34444	·34722	20
21	·35	·35277	·35555	·35833	·36111	·36388	21
22	·36666	·36944	·37222	·375	·37777	·38055	22
23	·38333	·38611	·38888	·39166	·39444	·39722	23
24	·4	·40278	·40555	·40833	·41111	·41388	24
25	·41666	·41944	·42222	·425	·42777	·43055	25
26	·43333	·43611	·43888	·44166	·44444	·44722	26
27	·45	·45278	·45555	·45833	·46111	·46388	27
28	·46666	·46944	·47222	·475	·47777	·48055	28
29	·48333	·48611	·48888	·49166	·49444	·49722	29
30	·5	·50277	·50555	·50833	·51111	·51388	30
31	·51666	·51944	·52222	·525	·52777	·53055	31
32	·53333	·53611	·53888	·54166	·54444	·54722	32
33	·55	·55278	·55555	·55833	·56111	·56388	33
34	·56666	·56944	·57222	·575	·57777	·58055	34
35	·58333	·58611	·58888	·59166	·59444	·59722	35
Min.	0″	10″	20″	30″	40″	50″	Min.

DECIMAL EQUIVALENTS OF A DEGREE—*continued.*

Min.	0″	10″	20″	30″	40″	50″	Min.
36	·6	·60277	·60555	·60833	·61111	·61388	36
37	·61666	·61944	·62222	·625	·62777	·63055	37
38	·63333	·63611	·63888	·64166	·64444	·64722	38
39	·65	·65277	·65555	·65833	·66111	·66388	39
40	·66666	·66944	·67222	·675	·67777	·68055	40
41	·68333	·68611	·68888	·69166	·69444	·69722	41
42	·7	·70277	·70555	·70833	·71111	·71388	42
43	·71666	·71944	·72222	·725	·72777	·73055	43
44	·73333	·73611	·73888	·74166	·74444	·74722	44
45	·75	·75277	·75555	·75833	·76111	·76388	45
46	·76666	·76944	·77222	·775	·77777	·78055	46
47	·78333	·78611	·78888	·79166	·79444	·79722	47
48	·8	·80277	·80555	·80333	·81111	·81388	48
49	·81666	·81944	·82222	·825	·82777	·83055	49
50	·83333	·83611	·83888	·84166	·84444	·84722	50
51	·85	·85277	·85555	·85833	·86111	·86388	51
52	·86666	·86944	·87222	·875	·87777	·88055	52
53	·88333	·88611	·88888	·89166	·89444	·89722	53
54	·9	·90277	·90555	·90833	·91111	·91388	54
55	·91666	·91944	·92222	·925	·92777	·93055	55
56	·93333	·93611	·93888	·94166	·94444	·94722	56
57	·95	·95277	·95555	·95833	·96111	·96388	57
58	·96666	·96944	·97222	·975	·97777	·98055	58
59	·93333	·98611	·98888	·99166	·99444	·99722	59
Min.	0″	10″	20″	30″	40″	50″	Min.

APPROXIMATION ("TRIAL AND ERROR") FOR ANY POWER ABOVE THE SQUARE.

N = the number out of which the root is to be extracted.
n = the nearest root first taken.
r = Index of the root required.
R = Root required.

$$R = n \frac{N(r+1) + n^r(r-1)}{N(r-1) + n^r(r+1)}.$$

The process is to be repeated, taking the results of the first approximation for the second trial, &c.

Differential and Integral Calculus.

Paragraphs which refer to the *Differential Calculus are in italics*; **those which refer to the Integral Calculus are in full-face type**; those which refer to both are in ordinary type.

The object of the Differential Calculus is to find how the indefinitely small changes in some VARIABLE *quantity alter at each instant the value of a quantity* DEPENDENT *upon it.*

The object of the Integral Calculus (the reverse of the Differential) is to ascertain from the ratio of indefinitely small changes in two or more magnitudes the function (f) which governs the changes.

Notation.

Constant quantities, which retain the same value throughout the investigation, are usually represented by the early letters of the alphabet—a, b, c, e, &c.

Variables, to which different values may be assigned, by the later letters, u, v, w, x, y, z. The latter are frequently (but not invariably) used to denote the following:

u = one or more functions; sometimes u = length; v = volume; x = abscissa; y = ordinate; z = surface, or area; d = differential, or the sign of differentiating; $\int$ is the sign of integration of the quantity that follows it: $\int\int\int$ = successive integration; $\int_b^a$ denotes that the integration is to be within the limits of a and b.

Rules for Differentiation and Integration

Rule for Differentiation of any power of the variable x.—Deduct 1 from the index of the variable, and multiply by the original index, or $d\,x^n = n\,x^{n-1}.\,d\,x$. For example, $d\,a\,x^3 = 3\,a\,x^{3-1} = 3\,a\,x^2.\,d\,x$.

Rule for Integration.—Add 1 to the index of the variable, and divide by the new index,* or $\int x^n\,d\,x = \frac{x^{n+1}}{n+1}$. For example, $\int 3\,a\,x^2\,d\,x \cdot \cdot \frac{3\,a\,x^{2+1}}{3} = a\,x^3$.

A constant, if a coefficient to a variable, is unchanged in differentiating; thus $d\,.\,a\,x^3 = 3\,a\,x^2\,.\,d\,x$.

If the constant be a term, it disappears; thus $d\,(a + x^3) = 3\,x^2\,.\,d\,x$.

A constant factor may be removed from the process of integration, thus, $\int a\,d\,x = a\,.\int.\,d\,x$.

A constant term must reappear in integration in the form of an arbitrary constant, thus, $\int 3\,x^2\,d\,x = x^3 + C$.

$\int$ and d neutralize each other, thus, $\int.\,d\,x = x$.

* Except when $n = -1$; then $\int x^{-1}\,d\,x = \int \frac{d\,x}{x} = \log_e x$.

Differential and Integral Calculus—*continued.*

Radical expressions must be represented by fractional indices, thus $\sqrt[3]{x^2}$ must be expressed as $x^{\frac{2}{3}}$; $\frac{1}{\sqrt{x}}$ as $x^{-\frac{1}{2}}$; $\sin.^{-1} x$, $\cos.^{-1} x$, &c., denote the arc whose sine or cosine, &c., is x.

Differential Coefficients.			Integrals.
If $u =$	*then* $\frac{du}{dx} =$	*and* $du =$	
$a.$	$o.$	$o.$	
x	1	dx	$\int dx = x + C$
nx	n	ndx	$\int ndx = nx + C$
x^n	nx^{n-1}	$nx^{n-1}\,dx$	$\int nx^{n-1}\,dx = x^n + C$
x^2	$2x$	$2x.dx$	$\int 2ax.dx = ax^2 + C$
x^3	$3x^2$	$3x^2\,dx$	$\int 3ax^2.dx = ax^3 + C$
$-x^{-\frac{1}{2}}$	$\frac{1}{2}x^{-\frac{3}{2}}$	$\frac{1}{2}x^{-\frac{3}{2}}\,dx$	$\int \frac{1}{2}ax^{-\frac{3}{2}}dx = -ax^{-\frac{1}{2}} + C$
$\frac{1}{x^{\frac{2}{3}}} = x^{-\frac{2}{3}}$	$-\frac{2}{3}x^{-\frac{5}{3}}$	$-\frac{2}{3}x^{-\frac{5}{3}}\,dx$	$\int -\frac{2}{3}ax^{-\frac{5}{3}}dx = ax^{-\frac{2}{3}} + C$
ax^2+bx+c	$2ax+b$	$(2ax+b)\,dx$	$\int (2ax+b)\,dx = ax^2+bx+C$
$log._b\,x$	$\frac{*m}{x}$	$\frac{m}{x}\,dx$	$\int \frac{m}{x}dx = log._b\,x + C$
$\dagger log._\epsilon\,x$	$\frac{1}{x}$	$\frac{dx}{x}$	$\int \frac{dx}{x} = log._\epsilon\,x + C$
a^x	$a^x\,log._\epsilon\,a$	$a^x\,log._\epsilon\,adx$	$\int a^x\,log._\epsilon\,adx = a^x + C$
$sin.\,x$	$cos.\,x$	$cos.\,xdx$	$\int cos.\,xdx = +\,sin.\,x + C$
$cos.\,x$	$-\,sin.\,x$	$-\,sin.\,xdx$	$\int sin.\,xdx = -\,cos.\,x + C$
$tan.\,x$	$\frac{1}{cos.^2\,x}$	$\frac{dx}{cos.^2\,x}$	$\int \frac{dx}{cos.^2\,x} = +\,tan.\,x + C$
$cot.\,x$	$-\frac{1}{sin.^2\,x}$	$-\frac{dx}{sin.^2\,x}$	$\int \frac{dx}{sin.^2\,x} = -\,cot.\,x + C$
$sec.\,x$	$\frac{sin.\,x}{cos.^2\,x}$	$\frac{sin.\,xdx}{cos.^2\,x}$	$\int \frac{sin.\,xdx}{cos.^2\,x} = +\,sec.\,x + C$
$cosec.\,x$	$-\frac{cos.\,x}{sin.^2\,x}$	$-\frac{cos.\,x.dx}{sin.^2\,x}$	$\int \frac{cos.\,xdx}{sin.^2\,x} = -\,cosec.\,x + C$

* *m is the modulus of the system of logarithms having a base b.*

† *ϵ = the number whose hyp. log. is* $1 = 2{\cdot}7182816$.

DIFFERENTIAL AND INTEGRAL CALCULUS—*continued.*

DIFFERENTIATION OF VARIOUS EXPRESSIONS OF v, y, w, &c., functions of the variable x.

	If $u =$	then $\frac{du}{dx} =$
Sum of several functions ..	$v + y - w$ &c.	$\frac{dv}{dx} + \frac{dy}{dx} - \frac{dw}{dx}$ &c.
Product of two functions ..	$v.y$	$v\frac{dy}{dx} + y\frac{dv}{dx}$
Product of more than two functions	$v.y.w$	$v.w.\frac{dy}{dx} + w.y\frac{dv}{dx} + v.y\frac{dw}{dx}$
Fraction	$\frac{y}{v}$	$\left[\left(v\frac{dy}{dx}\right) - \left(y\frac{dv}{dx}\right)\right] \div v^2$
Power	y^n	$n.y^{n-1}\frac{dy}{dx}$
Fractional power	$y^{\frac{n}{m}}$	$\frac{n}{m}y^{\frac{n}{m}-1}\frac{dy}{dx}$
Negative power	y^{-n}	$-n y^{n-1}\frac{dy}{dx}$
Function of a function ..	$f(y)$	$\frac{du}{dy} \cdot \frac{dy}{dx}$

SUCCESSIVE DIFFERENTIATION.

Successive differentiation is the process of differentiating successive differential coefficients of an original function.

Thus if $u = a x^5$	3*rd coefficient* $= \frac{d^3 u}{d x^3} = 60\ a x^2$
1*st coefficient* $= \frac{du}{dx} = 5 a x^4$	4*th* ,, $= \frac{d^4 u}{d x^4} = 120 a x$
2*nd* ,, $= \frac{d^2 u}{d x^2} = 20 a x^3$	5*th* ,, $= \frac{d^5 u}{d x^5} = 120 a$ &c.

In the numerators given in the example above $d^2 u$, $d^3 u$, &c., the indices are simply the symbols of successive differentiation.

If $u = a^x$; then $\frac{du}{dx} = \log._e a . a^x$; $\frac{d^2 u}{d x^2} = (\log._e a)^2 a^x$;
$\frac{d^3 u}{d x^3} = (\log._e a)^3 a^x$; $\frac{d^4 u}{d x^4} = (\log._e a)^4 a^x$; &c.
where e = number whose hyp. log. is $1 = 2{\cdot}71828$

If $u = \log._e x$; then $\frac{du}{dx} = +\frac{1}{x}$; $\frac{d^2 u}{d x^2} = -\frac{1}{x^2}$; $\frac{d^3 u}{d x^3} = +\frac{1.2}{x^3}$;
$\frac{d^4 u}{d x^4} = -\frac{1.2.3}{x^4}$; $\frac{d^5 u}{d x^5} = +\frac{1.2.3.4}{x^5}$; &c.

If $u = \sin. x$; then $\frac{du}{dx} = +\cos. x$; $\frac{d^2 u}{d x^2} = -\sin. x$;
$\frac{d^3 u}{d x^3} = -\cos. x$; $\frac{d^4 u}{d x^4} = +\sin. x$; $\frac{d^5 u}{d x^5} = +\operatorname{cosin} x$; &c.

DIFFERENTIAL AND INTEGRAL CALCULUS—*continued.*

FORMULÆ FOR SUCCESSIVE DIFFERENTIATION.

Let N = number of times to which successive differentiation is to be carried.

If $u =$	then $\frac{d^N u}{d x^N} =$
x^n	$n(n-1) \ldots\ldots [n-(N-1)]\, x^{n-N}$
x^{-n}	$(-1)^N n(n+1) \ldots\ldots n+(N-1)\, x^{-(n+N)}$
a^x	$(\log._\epsilon a)^N a^x$
$\sin. nx$	$n^N \sin.(nx + \frac{1}{2} N\pi)$
$\log. x$	$(-1)^{N-1} (N-1)(N-2) \ldots\ldots 3.2.1.\, x^{-N}$
$\frac{1+x}{1-x}$	$2(1-x)^{-(N+1)}\, N(N-1)(N-2) \ldots\ldots 3.2.1$

TAYLOR'S AND MACLAURIN'S THEOREMS.

Let y be a function of x which it is possible to develop in a series of ascending powers of that variable; and suppose that h = any indeterminate quantity, $y = A + Bx + Cx^2 + Dx^3 + Ex^4 +$ &c.; and when x becomes $x + h$, let $y = y'$,

$$y' = y + \frac{dy}{dx} h + \frac{d^2y}{dx^2} \cdot \frac{h^2}{1\times 2} + \frac{d^3y}{dx^3} \cdot \frac{h^3}{1\times 2\times 3} + \frac{d^4y}{dx^4} \cdot \frac{h^4}{1\times 2\times 3\times 4} + \&c.,$$

or "Taylor's Theorem";

$$y^1 = (y)_0 + \left(\frac{dx}{dy}\right)_0 x + \frac{1}{1\times 2}\left(\frac{d^2y}{dx^2}\right)_0 \cdot x^2 + \frac{1}{1\times 2\times 3} \cdot \left(\frac{d^3y}{dx^3}\right)_0 x^3 + \&c.,$$

or "Maclaurin's Theorem."

$$\int_{x_0}^{x_1} \frac{dx}{x} = \text{hyp. log. } x_1 - \text{hyp. log. } x_0 = \text{hyp. log. } \frac{x_1}{x_0}$$

INTEGRATION BY PARTS.

$$\int x.dy = xy - \int y.dx$$

SIMPSON'S FORMULA OF QUADRATURES.

To find the approximate value of any integral of the form $\int z.dx$, where z is any function of x.

Find n values of z, corresponding to n equidistant values of x; such as $z_0\, z_1\, z_2\, z_3 \ldots\ldots z_{n-2}\, z_{n-1}\, z_n$; then the value of the integral is the product of the third part of the equidistance, by a sum compounded of, (A) the extreme values of z; or $(z_0 + z_n)$; (B) the quadruple sum of the *odd* values of z; or $4(z_1 + z_3 + \ldots\ldots z_{n-1})$; (C) the double sum of the *even* values of z; or $2(z_2 + z_4 + \ldots\ldots z_{n-2})$; ... the nearer will be the approximation.

Differential and Integral Calculus—*continued.*

Maxima and Minima.

If a quantity increases continuously, and then decreases, its values, at the limits of increase or decrease, are the maxima or minima respectively. If it decreases (or increases) continually it has no maxima or minima.

The function u is a minimum or maximum when $\frac{du}{dx} = 0$.

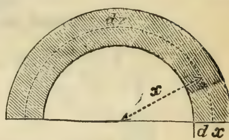
If the second differential coefficient $\frac{d^2 u}{d x^2}$ be a negative quantity the value of u is a maximum.

If $\frac{d^2 u}{d x^2}$ be positive, u is a minimum.

The point of contrary flexure (in a curve whose equation is $f(xy) = 0$) occurs when $\frac{d^2 y}{d x^2} = 0$ or $= \infty$.

Simple Example of the Application of the Principles of the Calculus to Increase in Area.

x = Radius = 12.
dx = Rate of increment of x.
z = Area of figure.
dz = Rate of increment of area = hatched portion in diagram.



Differential Calculus.—A figure increases at the rate $dx = 2$ *when* $x = 12$; *at what rate* dz *does the area increase when* $z = a x^2$ *and* $a = \frac{1}{2}\pi = 1.5708$? $dz = 2 a x^{2-1} dx = 2 a x . dx = 75.4$.

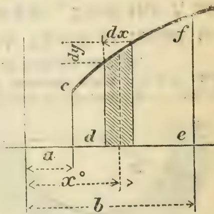
Example in Integration.—A figure is found to increase in the ratio $\frac{dz}{dx} = 2 a x$. Find the f, or function; $\int dz = \int 2 a x dx = \frac{2 a x^{1+1}}{2} = a x^2$.

Note.—In this and other diagrams given to exemplify the principles of the calculus the increments are shown as having considerable magnitude, otherwise they cannot be shown in diagram; but properly the increments should be indefinitely small.

Differential and Integral Calculus—*continued.*

$$d\,x^n = n\,x^{n-1}\,d\,x; \qquad \int x^n\,d\,x = \frac{x^{n+1}}{n+1}.$$

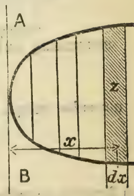
Simple Example of the Integration between Fixed Limits.



Let x and y be any co-ordinates.
b and a = the greatest and least values of x.

$\int_a^b y\,d\,x$ = the area of the figure $c\,d\,e\,f$.

Application of the Calculus to Areas and Centres of Gravity.

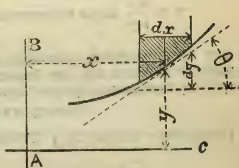


z = Area of one of the layers parallel to plane A B.
x = Distance of centre of layer from the plane A B.
$d\,x$ = Thickness of one layer.
V = Volume of the whole body = sum of volumes of the layers = $\int z\,d\,x$.

Distance of centre of gravity from

$$\text{plane A B} = \frac{\int x\,z\,d\,x}{V}.$$

Application of Calculus to Curves.



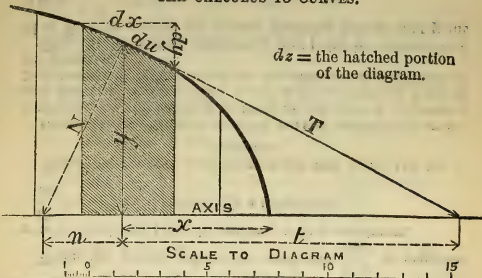
Let A B, A c, be the axes of the co-ordinates of the curve, x and y the co-ordinates.

$\phi\,(x\,y) = 0$ = the equation of the curve.

$$\text{Tan. } \theta = \frac{d\,y}{d\,x}.$$

Differential and Integral Calculus—*continued.*

Example of the application of the Calculus to Curves.



Let A = Major axis of an ellipse .. .. .. = say 40.
a = Minor axis of ditto .. .. .. = say 20.
y = Any ordinate .. .. = 7·1414.
x = Any abscissa corresponding with y = 6.

Then the equation of an ellipse being $y^2 = \frac{a^2}{A^2}(A x - x^2)$;

therefore $\frac{a^2 A x}{A^2} - \frac{a^2 x^2}{A^2} - y^2 = 0 = 10 x - \frac{x^2}{4} - y^2$,

the differential of which is $10 - \frac{x}{2} - 2 y = \frac{20 - x - 4 y}{2}$

and $\frac{d y}{d x} = \frac{20 - x}{4 y} = \cdot 491$; also $\frac{d x}{d y} = \frac{4 y}{20 - x} = 2 \cdot 04$.

Length of tangent $T = y \sqrt{1 + \left(\frac{d x}{d y}\right)^2} = 16 \cdot 225$

„ subtangent $t = y \frac{d x}{d y} = 14 \cdot 568$

„ normal $N = y \sqrt{1 + \left(\frac{d y}{d x}\right)^2} = 7 \cdot 955$

„ subnormal $n = y \frac{d y}{d x} = 3 \cdot 506$

Tan. of angle of T with $t = \frac{d y}{d x} = \cdot 491 = \tan. 26^\circ 10'$

Note.—$d x$, $d y$, &c., in this and in the preceding diagrams are shown as having considerable magnitude, but properly they should be *indefinitely small*

DIFFERENTIAL AND INTEGRAL CALCULUS—*continued.*

$$d x^n = n x^{n-1} d x; \qquad \int x^n d x = \frac{x^{n+1}}{n+1}.$$

SIMPLE EXAMPLE OF MAXIMA AND MINIMA.

u is a minimum or maximum when $\frac{d u}{d x} = 0$.

In formula $S = \frac{W}{2 D L}(L x - x^2)$ (see page 171); find the point at which the strain is a maximum.

$\frac{W}{2 D L}$ is the same in all cases, and therefore a constant; substitute a for it; and u for S; or $u = a L x - a x^2$;

then $\frac{d u}{d x} = a L x^{1-1} - 2 a x^{2-1} = a L - 2 a x$.

Make $\frac{d u}{d x}$ (or $a L - 2 a x) = 0$;

then $2 a x = a L$; or $2 x = L$; or $x = \frac{L}{2}$; or the point of maximum or minimum value is at half the span.

When the second differential coefficient $\frac{d^2 u}{d x^2}$ is negative, u is a maximum; but if positive, u is a minimum.

$\frac{d^2 u}{d x^2} = -2 a$; therefore u is a maximum.

EXAMPLE OF THE APPLICATION OF THE CALCULUS TO GIRDERS.

In any girder (whether straight, curved, continuous, or discontinuous) if the bending moment at any point be expressed as a function of a variable x, the normal shearing force at that point will be expressed by the differential coefficient of the function.

Thus, if the bending moment at any point be expressed by $M = W(2 a x - x^2)$; the normal shearing force at that point will be $\frac{d M}{d x} = W(2 a - 2 x) = 2 W(a - x)$.

Properties of the Circle.

Diameter .. × 3·14159 = circumference.
Diameter .. × ·886226 = side of an equal square.
Diameter .. × ·7071 = side of an inscribed square.
Diameter² .. × ·7854 = area of circle.
Radius .. .. × 6·28318 = circumference.
Circumference × ·31831 = diameter.

Circumference = 3·5449 $\sqrt{\text{area of circle}}$.

Diameter .. = 1·1283 $\sqrt{\text{area of circle}}$.

Length of arc = number of degrees × ·017453 radius.

Arc of 1° to rad. 1 = 0·01745329.
Arc of 1′ to rad. 1 = ·000290888.
Arc of 1″ to rad. 1 = ·000004848.

Degrees in arc whose length = radius = 57°·2957795.

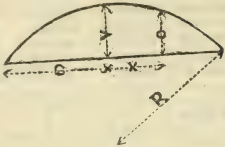
Value of π (or Ratio of Diameter to Circumference).

$\pi = 3{\cdot}14159265358979323846264338327950 +$

Log. $\pi = 0{\cdot}4971499$	$\pi\sqrt{2} = 4{\cdot}44288$	$\frac{\sqrt{2}}{\pi} = 0{\cdot}4501582$
$\frac{360}{\pi} = 114{\cdot}59156$	$\sqrt{\frac{2}{\pi}} = 0{\cdot}7978846$	$\frac{1}{\pi^2} = 0{\cdot}1013212$
$\frac{\pi}{360} = {\cdot}00872664$	$\frac{\pi}{\sqrt{2}} = 2{\cdot}2214415$	$\frac{1}{\sqrt{\pi}} = 0{\cdot}5641896$
$\frac{1}{\pi^2} = 0{\cdot}1013212$	$\sqrt{\frac{\pi}{2}} = 1{\cdot}2533$	
$\frac{1}{\sqrt{\pi}} = 0{\cdot}5641896$		

n.	$\pi \times n$.	$\frac{\pi}{n}$.	$\frac{n}{\pi}$.	$\pi^2 \times n$.	$\frac{\pi^2}{n}$.	$n\sqrt{\pi}$.
1	3·14159	3·14159	·31831	9·8696	9·8696	1·7725
2	6·28318	1·57080	·63662	19·7392	4·9348	3·5449
3	9·42478	1·04720	·95493	29·6088	3·2898	5·3174
4	12·56637	·785398	1·27324	39·4784	2·4674	7·0898
5	15·70796	·628318	1·59155	49·3480	1·9739	8·8623
6	18·84956	·523599	1·90986	59·2176	1·6449	10·6347
7	21·99115	·448798	2·22817	69·0872	1·4099	12·4072
8	25·13274	·392699	2·54648	78·9568	1·2337	14·1796
9	28·27433	·349065	2·86479	88·8264	1·0966	15·9521

Segment of Circles.



V = Versed sin. C = Semichord.
R = Radius. O = Any ordinate
X = Distance of ordinate from centre.

$$O = \sqrt{R^2 - X^2} - (R - V).$$

$$R = \frac{V^2 + C^2}{2\,V} \text{ or diameter } \frac{V^2 + C^2}{V}.$$

$$V = R - \sqrt{R^2 - C^2}.$$

$$X = \sqrt{R^2 - (O + R - V)^2}.$$

$$\text{Area of segment} = \frac{4\,V}{3}\sqrt{(0{\cdot}626\,V)^2 + C^2}.$$

Conic Sections.

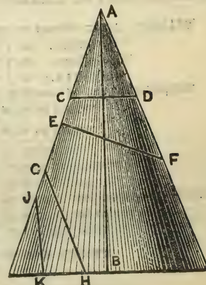
Section on plane A B, the line of axis forms a Triangle.

Ditto on C D, parallel to the base forms a Circle.

Ditto on E F at an angle to the base forms an Ellipse.

Ditto on G H, parallel to the slope of the cone forms a Parabola.

Ditto on J K, cutting the side at an angle less than parabola forms a Hyperbola.



Conic Sections.

Diagrams and Formulæ corresponding with the Symbols are given in succeeding pages.

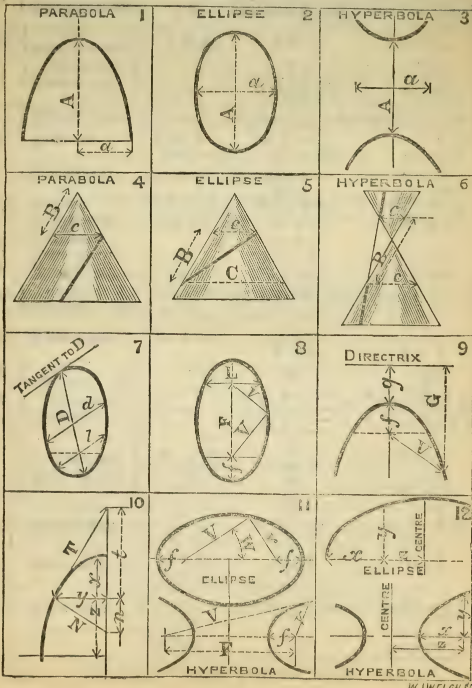
Symbol.	Definition.
A	Major Axis (or Transverse Axis) is the right line that passes through the vertices of a curve (Figs. 1, 2, 3).
a	Minor Axis (or Conjugate) is a right line passing through the centre of the major axis at right angles to it. In the parabola A and a are infinite; the symbols have therefore been adopted to express the height and $\frac{1}{2}$ the base respectively in the case of the parabola.
B	Slant Height of the portion of the cone that affects the figure (see Diagrams 3, 4, and 5).
C and c	Diameters of the Cone at the respective vertices of the figure (Figs. 4, 5, and 6).
D	Diameter of Curve is any straight line that passes through the centre of the curve and is terminated at both ends by the circumference (Fig. 7).
d	Conjugate Diameter to D.—A diameter is said to be conjugate to another when it is parallel to the tangent of that diameter.
F	Distance of Foci apart (Figs. 8 and 11).
f	Focal Distance, or distance of the focus from the nearest vertex (Figs. 8 and 11).
g	Distance of Vertex from Directrix.—The directrix is a line at right angles to the major axis, and is in such a position that $f : g :: V : G$ (Fig. 9).
G	Offset to Directrix from the end of any radius vector V (Fig. 9).
L	Latus Rectum (or Principal Parameter) passing through the focus, it is a double ordinate, which is a third proportion to the axis; or $A : a :: a : L$ (Fig. 8).

Conic Sections—*continued.*

Symbol.	Definition.
l	Parameter.—A third proportion to any diameter and its conjugate; or $D : d :: d : l$ (Fig. 7).
n	Subnormal.—The portion of the transverse axis subtended by the normal (Fig. 10).
N	Normal.—A line drawn at right angles to a tangent from the tangent point to the transverse axis (Fig. 10).
t	Subtangent.—That part of the transverse axis that is subtended by the tangent (Fig. 10).
T	Tangent.—A right line which touches the curve, and, being produced, does not cut it. The length of the tangent is limited between the point of contact and the transverse axis.
R	Radius of Curvature at any point of the curve.
V, v	Radii Vectores.—The radius vector is a straight line drawn from the focus to any point in the curve (Fig. 11).
W	Traced Angle.—The angle formed by the radius vector and the transverse axis (Fig. 11).
x	Abscissa.—The portion of the diameter which is between the ordinate and the curve.
y	Ordinate.—Any line parallel to the tangent of a diameter, and drawn from that diameter to the curve (Fig. 12).
z	Distance from Centre of curve to any ordinate (Fig. 12).

Conic Sections—*continued.*

Diagrams illustrating the Symbols used in the Definitions and Formulæ.



		Parabola.	Ellipse.	Hyperbola.
A*	Major axis	$\frac{a^2 B}{c^2}$	$\sqrt{B^2 + Cc}$	$\sqrt{B^2 - Cc}$
a*	Minor axis	$\sqrt{\frac{c^2 A}{B}}$	$\sqrt{Cc}$	$\sqrt{Cc}$
B	Slant height	$\frac{c^2 A}{a^3}$	$\sqrt{A^2 - a^2}$	$\sqrt{A^2 + a^2}$
C	Diam. of cone at vertices	..	$\frac{a^2}{c}$	$a^2 \div c$
c		$\sqrt{\frac{a^2 B}{A}}$	$\frac{a^2}{C}$	$a^2 \div C$
D	Conjugate diameters	..	$\sqrt{A^2 + a^2 - d^2}$	$\sqrt{A^2 - a^2 + d^2}$
d			$\sqrt{A^2 + a^2 - D^2}$	$\sqrt{A^2 - a^2 + D^2}$
F	Distance of foci	..	B	B
f	Focal distance	$y^2 \div 4x$	$\frac{A - F}{2}$	$\frac{F - A}{2}$
g	Distance of directrix	f	$f^2 \div \left(\frac{a^2}{2A} - f\right)$	$f^2 \div \left(\frac{a^2}{2A} - f\right)$
G	Offset to ditto	V	$gV \div f$	$gV \div f$
L	Latus rectum	$4f$	$a^2 \div A$	$a^2 \div A$
l	Parameter ..	..	$d^2 \div D$	
n	Subnormal	$y^2 \div t$	$y^2 \div t$	$y^2 \div t$
N	Normal ..	$\sqrt{y^2 + n^2}$	$\sqrt{y^2 + n^2}$	$\sqrt{y^2 + n^2}$
t	Subtangent	$2x$	$\frac{A^2}{4z} - z$	$z - \frac{A^2}{4z}$
T	Tangent ..	$\sqrt{y^2 + t^2}$	$\sqrt{y^2 + t^2}$	$\sqrt{y^2 + t^2}$
V v	Radius vector	$x + f$	$\sqrt{(x - f)^2 + y^2}$	$\sqrt{(x - f)^2 + y^2}$
R	Radius of curvature	..	$\frac{4\sqrt{(Vv)^3}}{Aa}$	$\frac{4\sqrt{(Vv)^3}}{Aa}$
W	Sine of traced angle ..	$y \div V$	$y \div V$	$y \div V$
x	Abscissa from a vertex ..	$\frac{Ay^2}{a^2}$	$\frac{A(a \pm \sqrt{a^2 - 4y^2})}{2a}$	$\frac{A(a \pm \sqrt{a^2 + 4y^2})}{2a}$
y	Ordinate ..	$\frac{a\sqrt{x}}{\sqrt{A}}$	$\frac{a}{A}\sqrt{Ax - x^2}$	$\frac{a}{A}\sqrt{x(A + x)}$
z	Distance of y from centre	..	$\frac{A}{2} - x$	$\frac{A}{2} + x$

* In the parabola A = height; $a = \frac{1}{2}$ base.

Loci. (Paget Higgs.)

Straight Line.—The locus of a point which moves in a given direction, and so as to pass through a given position.

Circle.—The locus of every point in a given plane which is at a given distance from a given point in that plane. The given point is the centre.

Ellipse.—The locus of every point in a plane such that the sum of its distances from two given points in that plane is equal to a given length. This locus is called the ellipse; the two points its foci.

Hyperbola.—The locus of every point in a plane so situated that the difference of its distances from two given points in that plane is equal to a given length.

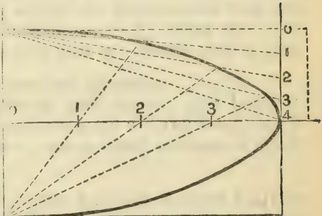
Parabola.—The locus of every point in a plane which is equally distant from a given point and a given straight line in that plane. The point is the focus; given line the directrix.

It is useful to note that the square root of any number may be constructed as the third side of a right triangle, of which the hypothenuse and one leg are respectively the halves of the numbers next above and next below the given number. Also that Euclid's Pons Asinorum appears more usefully stated as that the square of a line is equal to the sum of the squares of its projections on two rectangular axes.

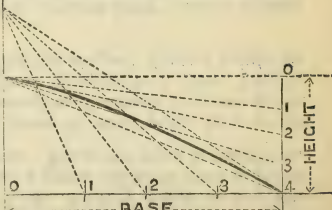
Construction of Ellipse, Hyperbola, and Parabola, by Intersecting Straight Lines.

Any convenient number of equal divisions may be taken, and the intersections of straight lines as indicated in the diagrams will give points in the curve.

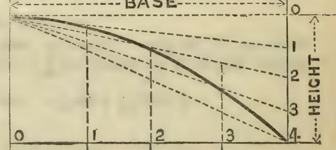
ELLIPSE.
Divide half minor and half major axes. Intersecting lines radiate from end of minor axis.



HYPERBOLA.
Divide height and base. Intersecting lines radiate from end of major axis and vertex.

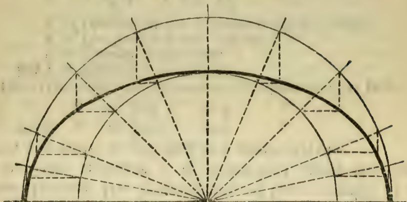


PARABOLA.
Divide height and base. Intersecting lines vertical, and radiating from vertex.



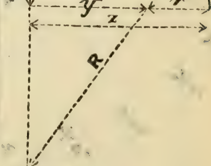
ELLIPSE—*continued.*

TO CONSTRUCT AN ELLIPSE FROM TWO CIRCLES



Describe two semicircles whose diameters are respectively the length of the major and minor axes. The intersection of the horizontal and vertical lines drawn from any radial line will give a point in the curve.

TO CALCULATE THE RADIUS OF A FALSE ELLIPSE WITH 3 CENTRES.

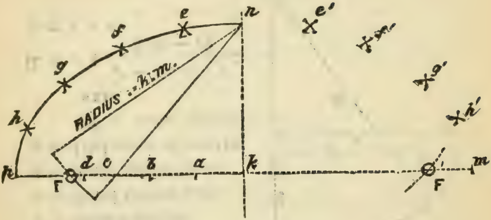


R = Large radius.
r = Small radius.
x = Semi minor axis.
z = Semi major axis.
y = Distances of centre of r from minor axis.

$$R = x + \frac{y^2 - (x - r)^2}{2(x - r)};$$

$$y = z - r.$$

Ellipse—*continued.*



To draw an Ellipse:

From n, with radius $n\,F$ = semi-transverse axis $k\,m$, draw a circle, cutting the transverse axis at F F′. F F′ are the foci of the ellipse.

On the transverse axis lay off any points $a\ b\ c\ d$, between the foci, and

From F with radius $= p\,a$ describe a portion of a circle at e, also from F′ with radius $= m\,a$ describe a portion of a circle at e; the curve will pass through the intersection of these circles at e.

In like manner f is described from the foci with the radii $= p\,b$ and $m\,b$ respectively

g with „ $= p\,c$ „ $m\,e$ „
h „ „ $= p\,d$ „ $m\,d$ „

To Calculate any Ordinate (see diagram next page).

Let T = Semi-transverse axis.
C = Semi-conjugate axis.
K = The length of any ordinates
X = Distance of the ordinate from the centre.

$$K = \sqrt{C^2 - \left(\frac{CX}{T}\right)^2}.$$

Area of an ellipse = T C 3·1416.

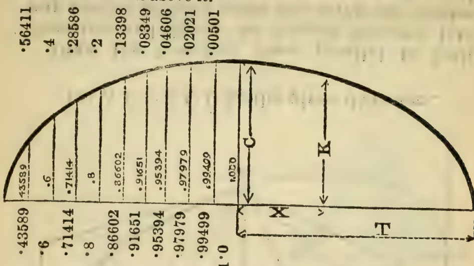
Periphery of an ellipse *approximately*

$$= \tfrac{1}{2}\pi\left[\sqrt{2(T^2 + C^2)} + T + C\right] + 0\cdot2078\,(T - C).$$

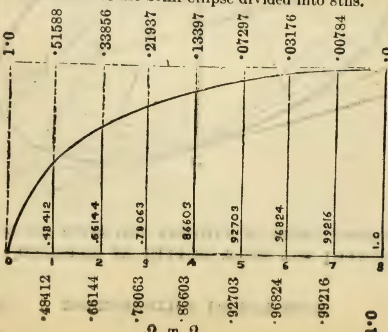
Ellipse—*continued.*

To Construct an Ellipse by Ordinates.

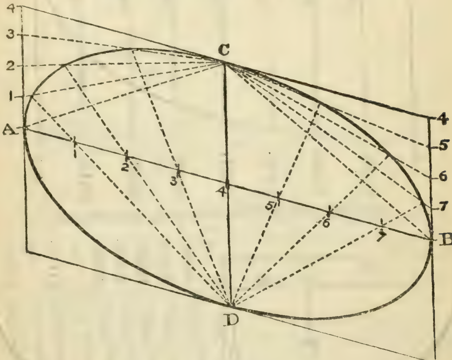
Divide the semi-transverse axis into 10 equal parts, and draw ordinates. The length of these ordinates = the semi-conjugate axis C, multiplied by the respective numbers on each ordinate in the diagram. The complement of each ordinate is shown above it.



Ordinates of the Semi-ellipse divided into 8ths.



To Construct an Ellipse when the Diameters do not cross one another at Right Angles.



Let A B and C D be the given diameters.

Draw the bounding lines parallel to both diameters and divide the longest diameter into any number of equal parts, also divide the shorter bounding lines into the same number of equal parts. From one end of the shorter diameter D draw radial lines *through* the divisions of the longer diameter, and from the opposite end C draw radial lines to the divisions on the shorter bounding lines; the intersection of these lines will give points in the curve.

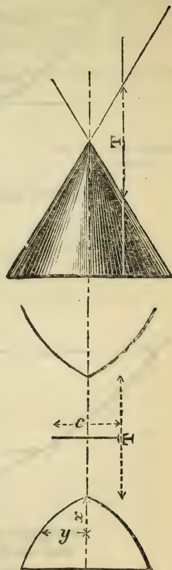
HYPERBOLA.

The transverse axis of a hyperbola $a\,b$ is that part of the axis which, if continued, would join an opposite cone.

The conjugate axis is a line drawn through the centre of the transverse axis at right angles to it.

The parameter is the chord of the curve drawn through the focus at right angles to the axis.

The focus is a point in the axis where the ordinate is $= \frac{1}{2}$ diameter.



T = Transverse axis.

C = Conjugate axis.

x = Abscissa.

y = Ordinate.

$$y = \frac{C\sqrt{x\,(T+x)}}{T}.$$

$$x = \frac{T\sqrt{y^2 + \left(\frac{C}{2}\right)^2}}{C} - \frac{T}{2}.$$

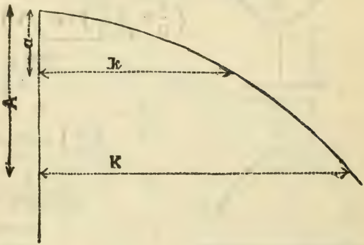
$$C = \frac{T\,y}{\sqrt{x\,(T+x)}}.$$

$$T = \frac{C\,x\left(\sqrt{y^2 + \left(\frac{C}{2}\right)^2} + \frac{C}{2}\right)}{y^2}.$$

$$\text{Parameter} = \frac{C^2}{T}.$$

Parabola.

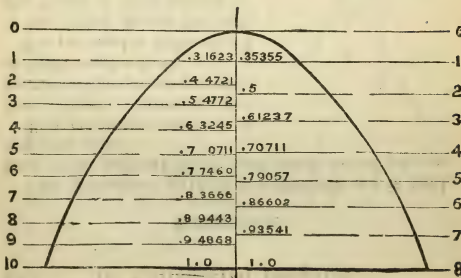
A and a = the abscissæ.
K and k = the ordinates.



$$k = \frac{K\sqrt{a}}{\sqrt{A}}. \qquad a = \frac{A \times k^2}{K^2}.$$

Ordinates of the Parabola.

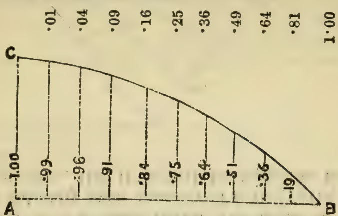
ABSCISSA DIVIDED IN 10THS. ABSCISSA DIVIDED IN 8THS.



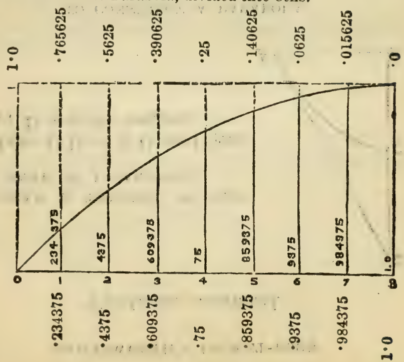
Parabola—*continued.*

CONSTRUCTION OF PARABOLIC CURVE.

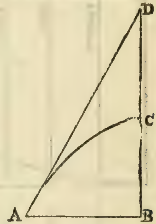
Divide the ordinate A B into 10 equal parts and raise perpendiculars, the length of which will be determined by multiplying the abscissa A C by the respective number on each perpendicular in the diagram. The complement of each ordinate is shown above it.



Ordinate of the Parabola, divided into 8ths.



PARABOLA—*continued.*

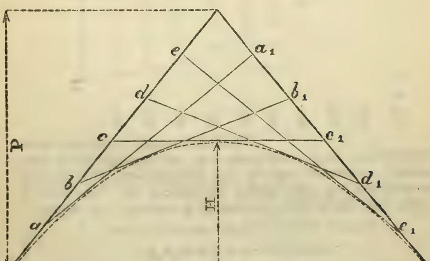


TO DRAW A TANGENT TO ANY PART OF A PARABOLA.

Make C D = B C and join D A; D A is the tangent.

TO CONSTRUCT A PARABOLA.

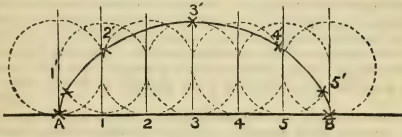
Make P = 2 H and divide the sides of the triangle into any even number of equal parts, join *a a*, *b b*, *c c*, &c., the lines will be tangents to the parabola.



Construction of the Cycloidal Curve.

On the line A B, lay off any point 1, 2, 3, 4, &c., draw perpendicular lines at each point, and on each describe circles equal to the generating circle.

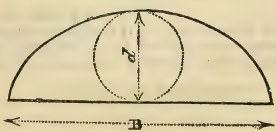
On the circum. of the circle at 1 lay off $1 \cdot 1' = A . 1$.
" " " 2 " $2 \cdot 2' = A . 2$.
" " " 3 " $3 \cdot 3' = A . 3$.
and so on; the points 1′, 2′, 3,′ 4′, 5′, are points of the curve.



See also another method of forming a cycloid, "Wave lines."

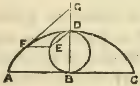
Calculation of the Cycloidal Curve.

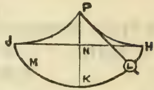
Length of base $B = 3 \cdot 14159\, d$.
Diameter of generating circle $d = \cdot 31831$ B.
Area of cycloid = area of generating circle × 3.
Length of curve = $4\, d$.



CYCLOIDAL CURVE—*continued.*

The area of A F D E B A is equal to that of the generating circle. The tangent F G is parallel to the chord D E. The arc D F is double the chord D E. The circular arc D E = F E parallel to the base A B.

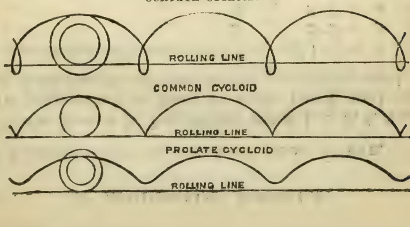




If the cycloid be turned upside down a body falls through any arc L K in the same time independently of the length of the arc; this time is to that of a body falling perpendicularly from N to K as 3·14159 to 2; and, if a pendulum be made to oscillate in the arc of a cycloid its vibrations will be isochronous. The evolute of a cycloid is another equal cycloid. The cycloid is the curve of quickest descent between any two points.

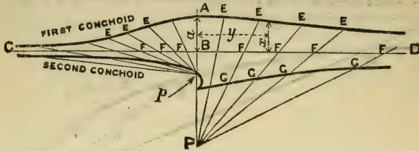
The cycloid is formed by a tracing point attached to a generating circle which rolls on a straight line. If the tracing point be beyond the circumference of the generating circle, a curtate cycloid will be produced terminating in nodes; if the tracing point be on the circumference a common cycloid will be formed terminating in cusps, if within the circumference a prolate cycloid will be formed.

CURTATE CYCLOID.



CURVES—*continued.*

CONCHOID CURVE.

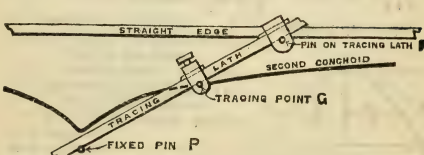


From the point P on the straight line P A lay off P B $= b$ = the distance of the generating point from the asymptote C D which is at right angles to P A; also lay off B A $= a =$ axis of the conchoid. Draw from P any radiating lines cutting the asymptote at F F F, and on these lines produced lay off F E, F E, &c., $= a$; these distances will give points in a "*first*" conchoid (or a conchoid on that side of the asymptote which is opposite to the generating point P).

For a second conchoid (or one formed on the same side as the generating point) the distances F G, F G, &c. $= a$ are laid off towards P; if b is less than a the curve will have a node at the centre, if $b = a$ it will have a cusp at the centre. The left-hand curve is drawn with p as the generating point; b being less than a.

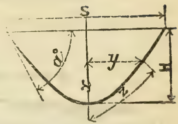
$$y = a^2 b^2 + 2 a^2 b x + a^2 x^2, \text{ for a first conchoid.}$$
$$= a^2 b^2 - 2 a^2 b x + a^2 x^2, \text{ for a second conchoid.}$$

MODE OF TRACING A CONCHOID CURVE.



For a first conchoid the tracing point must be in the prolongation of the lath above the straight-edge.

CURVES—*continued.* CATENARY.



$S =$ Span. $H =$ dip.
$x =$ Abscissa.
$y =$ Ordinate.
$z =$ Length of chain between vertex and ordinate.
$p =$ Parameter $=$ horizontal tension at vertex (or lowest point in the chain).
$t =$ Tension at point of suspension.
$a^\circ =$ Angle of suspension. $L =$ Length of the chain.

$$y = p\,(\text{hyp. log.}\ \frac{p + x + \sqrt{2px + x^2}}{p};\ = p\,(\text{hyp. log.}\ \frac{z+p}{z-p}.$$

$z = p \,.\, \tan.\, a^\circ$; $t = p \,.\, \sec.\, a^\circ$; $x = z \,.\, \text{cosec.}\, a^\circ \,.\, \text{versin.}\, a^\circ$.

If $L = 2\,S$, then $H = \cdot 7966\,S$, and $a^\circ = 77^\circ\ 3'$.

The tension at the point of suspension with respect to y is at a minimum when $a^\circ = 56^\circ\ 28'$; then if p be assumed $= 1$, then $x = \cdot 81$, $y = 1\cdot 995$, $z = 1\cdot 5089$.

Distance of centre of gravity chain $2\,z$ above vertex $=$

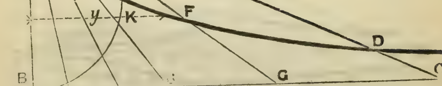
$$\frac{1}{2}\left(x + \frac{p\,y}{z} - p\right).$$

If $p = H = 1$, then $S = 2\cdot 6339$, $L = 3\cdot 4641$, $t = 2$, and $a^\circ = 60^\circ$.

CISSOID CURVE.

$x =$ Abscissa. $a =$ Axis $=$ A B. $y =$ Ordinate.

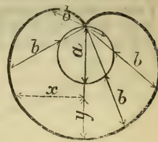
$$y = \sqrt{\frac{x^3}{a - x}}.$$



On A B describe a semicircle, and from A draw lines radiating to the asymptote B C, which is at right angles to A B; on these lines lay off J L = A K; G F = A H; C D = A E; &c.

CURVES—*continued*.

CARDIOIDE.



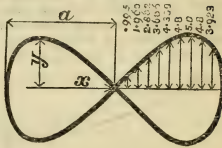
$a =$ Diameter of generating circle.
$x =$ Abscissa.
$y =$ Ordinate.

To construct a cardioide curve describe the generating circle and through one end of its diameter draw radiating lines, always making $b\ b\ b = a$.

The equation to the curve is as follows :—

$$y^4 - 6ay^3 + 2x^2y^2 - 6ax^2y + x^4 + 12a^2y^2 - 8a^3y + 3a^2x^2 = 0.$$

LEMNISCATE.

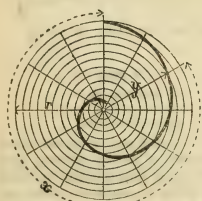


$x =$ Abscissa.
$y =$ Ordinate.
$a =$ Axis.

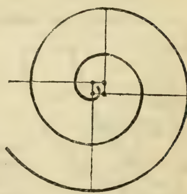
$$y = \frac{x\sqrt{a^2 - x^2}}{a}.$$

SPIRAL.

TRUE SPIRAL.



FALSE SPIRAL.

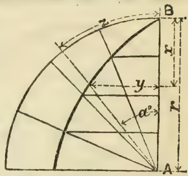


Divide the radius and the circumference into the same number of equal parts, then the intersection of the radial lines gives points in the curve. A false spiral is sometimes drawn in a series of quadrants from four centres.

$$y = \frac{x\,r}{\pi} = \cdot 159\,x.$$

CURVES—*continued.*

QUADRATRIX.

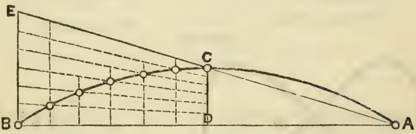


Divide the circumference of a quadrant and the radius A B into the same number of equal parts; then the intersection of the respective lines as drawn in the diagram gives points in the curve.

$$y = \frac{\sin. a\,(r - x)}{\sqrt{r^2 - \sin. a^2}}.$$

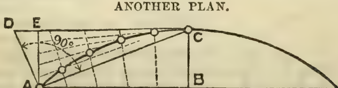
$$x = \cdot 0636\, r\, z.$$

PLAN OF SETTING OUT A CAMBER OR FLAT CURVE.



Join A C and produce the line A C until it cuts the perpendicular line B E. Divide the half span B D into any convenient number of parts, and on each division erect a perpendicular. Also divide B E into the same number of parts. Then lines radiating from the divisions on E B to the point A will at their intersection with the perpendiculars give points in the curve.

ANOTHER PLAN.



Join A C and draw the line A D at right angles to A C until it cuts the horizontal tangent line C D. Also draw A E perpendicular to the line A B. Divide the half chord A B into any convenient number of parts, also D C and A E into the same number of parts. Then lines radiating to C from the divisions on A E will at their intersection with the lines which join the divisions on A B and D C give points in the curve.

lines which join the divisions on A B and D C give points in the curve.

Curves—*continued*.

Equations of Curves.

The formula $A x^2 + B x y + C y^2 + D x + F = 0$, represents an ellipse, parabola, or hyperbola, according as $B^2 - 4 A C$ is *positive* in the ellipse; is 0 in the parabola; or negative in the hyperbola.

The following are the equations of the principal curves when $x =$ the abscissa, $y =$ the ordinate, $a =$ the axis, $p =$ the parameter.

Circle, $y = \sqrt{a x - x^2}$.

Ellipse, $y = \sqrt{\frac{p}{a}(a x - x^2)}$.

Hyperbola, $y = \sqrt{\frac{p}{a}(a x + x^2)}$.

Parabola, $y = \sqrt{p x}$.

Catenary, $y = p \left(\text{hyp. log.} \frac{p + x + \sqrt{2 p x + x^2}}{p} \right)$

1st Conchoid, $y = a^2 b^2 + 2 a^2 b x + a^2 x^2$
2nd Conchoid, $y = a^2 b^2 - 2 a^2 b x + a x^2$ } when $b =$ distance of the generating point from the asymptote (or P B, see diagram of Conchoid).

Cissoid, $y = \sqrt{\frac{x^3}{a - x}}$.

Cardioide, $y^4 - 6 a y^3 + 2 x^2 y^2 - 6 a x^2 y + x^4 + 12 a^2 y^2 - 8 a^3 y + 3 a^2 x^2 = 0$.

Lemniscate, $y = x \frac{\sqrt{a^2 - x^2}}{a}$.

Quadratrix, $y = \frac{\sin. \theta (r - x)}{\sqrt{r^2 - (\sin. \theta)^2}}$; where $\theta =$ the angle subtended by y, and $r =$ the radius of the generating circle.

Spiral, $y = \frac{r x}{c}$; where $c =$ the circumference of the circle in which the spiral makes one revolution, $r =$ the radius of ditto, $= x$ the distance of y from end of the spiral subtended by the circumference of the generating circle, $y =$ distance of any part of the spiral measured from its centre. (See Spiral.)

Mensuration of Surfaces.

Area of triangle .. = Base × ½ perpendicular.
" circle .. .. = Diameter² × ·7854.
" sector of circle = Length of arc × ½ radius.
" " " = $\dfrac{\text{Number of degrees in arc} \times \text{area of the circle}}{360}$

Area of parabola .. = Base × ⅔ height.

Frustum of a parabola = $\frac{2}{3}$ height $\dfrac{\text{base}^3 - \text{top}^3}{\text{base}^2 - \text{top}^2}$.

Area of ellipse .. .. = Transverse axis × ·7854 conjugate axis.
" cycloid.. .. = Area of generating circle × 3.
Surface of cylinder .. = Area of both ends + length × circumference.
" cone .. .. = Area of base + circumference of base × ½ slant height.
" sphere .. = Diameter² × 3·14159.
" frustum .. = Sum of girt at both ends × ½ slant height + area of both ends.

Segment Areas.

The area of a segment = Area of a sector − ½ chord × (radius − versin.).

Area of segment of circle = Diameter² × x (see Table).

$\frac{V}{D}$ = The versed sine divided by the diameter of the circle of which the segment is a part.

$\frac{V}{D}$	x	$\frac{V}{D}$	x	$\frac{V}{D}$	x	$\frac{V}{D}$	x	$\frac{V}{D}$	x
·01	·001329	·11	·047006	·21	·119898	·31	·207376	·41	·303187
·02	·003749	·12	·053385	·22	·128114	·32	·216666	·42	·313042
·03	·006866	·13	·059999	·23	·136465	·33	·226034	·43	·322928
·04	·010538	·14	·066833	·24	·144945	·34	·235473	·44	·332843
·05	·014681	·15	·073875	·25	·153546	·35	·244980	·45	·342783
·06	·019239	·16	·081112	·26	·162263	·36	·254551	·46	·352742
·07	·024168	·17	·088536	·27	·171090	·37	·264179	·47	·362717
·08	·029435	·18	·096135	·28	·180020	·38	·273861	·48	·372704
·09	·035012	·19	·103900	·29	·189048	·39	·283593	·49	·382700
·10	·040875	·20	·111824	·30	·198168	·40	·293370	·50	·392699

Mensuration of Solids.

Cylinder = Area of one end × length.

Sphere = Diameter $^3 \times 0 \cdot 5236$.

Segment of sphere $= 0 \cdot 5236\,H\,(H^2 + 3\,R^2)$, where H = height of segment and R = radius of the base of the segment.

Cone or pyramid = Area of base × $\frac{1}{3}$ perpendicular height.

Frustum $= \frac{1}{3}\,H \left(A + a + \sqrt{A \times a}.\right)$ When A and a = Areas of the ends, H = Perpendicular height.

Frustum of cone $= 0 \cdot 2618\,H\,(D^2 + d^2 + D.\,d)$. When D and d = the diameters of each end, H = Perpendicular height.

Wedge = Area of base × $\frac{1}{2}$ perpendicular height.

Frustum of wedge $= \frac{1}{2}\,H\,(A + a)$, when A and a = Area at each end, H = Perpendicular height.

Length of Helices and Spirals.

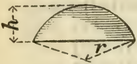
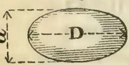
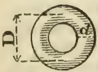
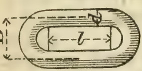
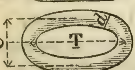
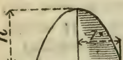
x = Length of any helix or screw coil.
l = Length of any plain spiral.
L = Length of any conical spiral.
C = Circumference of a circle equal in diameter to the diameter of the helix or largest diameter of the spiral.
c = Circumference of a circle equal the smallest diameter of the spiral.
n = Number of revolutions of helix or spiral.
p = Pitch of revolutions.
h = Height of the conical spiral.

$$x = n\sqrt{C^2 + p^2}.$$

$$l = n\left(\frac{C + c}{2}\right).$$

$$L = \sqrt{l^2 + h^2}.$$

SURFACE AND SOLIDITY OF BODIES.

		Convex Surface.	Solidity.
1		$\pi d^2 = 3{\cdot}14159\, d^2$	$\frac{\pi}{6} d^3 = {\cdot}5236\, d^3$
2		$6{\cdot}2832\, r\, h + 3{\cdot}14159 r \sqrt{r^2 - (r-h)^2}$	$2{\cdot}0944\, r^2 h$
3		$2\pi rh = 6{\cdot}2832\, rh$	$\frac{1}{3} \pi h^2 (3r - h)$
4		$3{\cdot}14159\, d \sqrt{\frac{D^2 + d^2}{2}}$	${\cdot}5236\, D d^2$
5		$\pi^2 D.d = 9{\cdot}8696\, D.d$	$(2{\cdot}46741\, D)\, d^2$
6		$\pi^2 D.d + 2\pi ld = 9{\cdot}87\, D{\cdot}d + 6{\cdot}28\, ld$	${\cdot}7854\, d^2 (3{\cdot}14159\, D + 2l)$
7		$\pi^2 d \sqrt{\frac{T^2 + C^2}{2}} = 9{\cdot}87\, d \sqrt{\frac{T^2 + C^2}{2}}$	$2{\cdot}4674 \sqrt{\frac{T^2 + C^2}{2}}$
8		$3.6\, r \sqrt{r^2 + \frac{4}{3} h^2}$	$1{\cdot}5708\, r^2 h$
9		$6{\cdot}2832\, r.l$ l = Length of generating line r = Radius of centre of gravity of generating line	$6{\cdot}2832\, r.a$ a = Area of generating surface r = Radius of centre of gravity of area

1. Sphere. 2. Sector of sphere. 3. Segment of sphere. 4. Ellipsoid. 5. Ring. 6. Link. 7. Elliptic link. 8. Paraboloid. 9. Any figure of revolution on axis.

Table of Polygons.

S = Side of polygon.
R = Radius of circumscribed circle.
r = Radius of inscribed circle.
A = Angle formed by the intersection of the sides.

Name.	No. of Sides.	A.	Area $= S^2 \times$	$S = R \times$	$S = r \times$
Trigon ..	3	60°	·4330	1·732	3·4641
Pentagon ..	5	108°	1·7205	1·1755	1·4536
Hexagon ..	6	120°	2·5980	1·0000	1·1547
Octagon ..	8	135°	4·8284	·7653	0·8284
Decagon ..	10	144°	7·6942	·6180	·6498

Area of any regular polygon = Radius of inscribed circle × $\frac{1}{2}$ number of sides × length of one side.

Table of Polyhedrons.

Name.	No. of Sides.	$R = S \times$	$r = S \times$	$A = S^2 \times$	$C = S^3 \times$
Tetrahedron	4	0·6124	·2041	1·7320	0·1178
Hexahedron	6	·8660	·5000	6·0000	1·0000
Octahedron .	8	·7071	·4082	3·4641	·4714
Dodecahedron	12	1·4012	1·1135	20·6458	7·6631
Icosahedron	20	·9510	·7558	8·6602	2·1817

S = Length of linear edge of a side.
R = Radius of circumscribed circle.
r = Radius of inscribed circle.
A = Area of polyhedron.
C = Cube contents of polyhedron.

New Standard Wire Gauge.

AREAS AND CIRCUMFERENCES OF WIRE OF NEW S. W. G. IN DECIMALS OF AN INCH.

S. W. G.	Area.	Circumference.	S. W. G.	Area.	Circumference.
7/0	·1963495	1·570796	23	·0004524	·075398
6/0	·1690931	1·457699	24	·0003801	·069115
5/0	·1465741	1·357168	25	·0003142	·062832
4/0	·1256637	1·256637	26	·0002545	·056549
3/0	·1086865	1·168672	27	·0002112	·051522
2/0	·0951149	1·093274	28	·0001720	·046496
0	·0824479	1·017876	29	·0001453	·042726
1	·0706858	·942478	30	·0001208	·038956
2	·0598285	·867080	31	·0001057	·036442
3	·0498759	·791681	32	·00009161	·033929
4	·0422733	·728850	33	·00007854	·031416
5	·0352989	·666018	34	·00006648	·028903
6	·0289529	·603186	35	·00005542	·026389
7	·0243285	·552920	36	·00004536	·023876
8	·0201062	·502655	37	·00003632	·021363
9	·0162860	·452389	38	·00002827	·018850
10	·0128680	·402124	39	·00002124	·016336
11	·0105683	·364425	40	·00001810	·015080
12	·0084949	·326726	41	·00001521	·013823
13	·0066476	·289027	42	·00001257	·012566
14	·0050265	·251327	43	·00001018	·011310
15	·0040715	·226195	44	·00000804	·010053
16	·0032170	·201062	45	·00000616	·008796
17	·0024630	·175929	46	·00000452	·007540
18	·0018096	·150796	47	·00000314	·006283
19	·0012566	·125664	48	·00000201	·005027
20	·0010179	·113097	49	·00000113	·003770
21	·0008042	·100531	50	·00000079	·003142
22	·0006158	·087965			

By order of Council the New Legal Standard Wire Gauge came into operation March 1st, 1884.

Areas of Small Circles, advancing by 32nds.

Diam.	Area.	Diam.	Area.	Diam.	Area.	Diam.	Area.
$\frac{1}{32}$	·00076	$\frac{9}{32}$	·0621	$\frac{17}{32}$	·2216	$\frac{25}{32}$	·4793
$\frac{1}{16}$	·0030	$\frac{5}{16}$	·0767	$\frac{9}{16}$	·2485	$\frac{13}{16}$	·5185
$\frac{3}{32}$	·0069	$\frac{11}{32}$	·0928	$\frac{19}{32}$	·2768	$\frac{27}{32}$	·5591
$\frac{1}{8}$	·0122	$\frac{3}{8}$	·1104	$\frac{5}{8}$	·3068	$\frac{7}{8}$	·6013
$\frac{5}{32}$	·0192	$\frac{13}{32}$	·1296	$\frac{21}{32}$	·3382	$\frac{29}{32}$	·6450
$\frac{3}{16}$	·0276	$\frac{7}{16}$	·1503	$\frac{11}{16}$	·3712	$\frac{15}{16}$	·6903
$\frac{7}{32}$	·0376	$\frac{15}{32}$	·1725	$\frac{23}{32}$	·4057	$\frac{31}{32}$	·7370
$\frac{1}{4}$	·0490	$\frac{1}{2}$	·1963	$\frac{3}{4}$	·4417	1	·7854

For Areas of Small Circles, advancing by decimals, see

AREAS OF CIRCLES, ADVANCING BY 8THS.

Diam.	·0	·$\frac{1}{8}$	·$\frac{1}{4}$	·$\frac{3}{8}$	·$\frac{1}{2}$	·$\frac{5}{8}$	·$\frac{3}{4}$	·$\frac{7}{8}$	Diam.
0	·0	·0122	·0490	·1104	·1963	·3068	·4417	·6013	0
1	·7854	·9940	1·227	1·484	1·767	2·073	2·405	2·761	1
2	3·142	3·546	3·976	4·430	4·908	5·411	5·939	6·491	2
3	7·069	7·669	8·295	8·946	9·621	10·32	11·04	11·79	3
4	12·57	13·36	14·18	15·03	15·90	16·80	17·72	18·66	4
5	19·64	20·62	21·64	22·69	23·75	24·85	25·96	27·10	5
6	28·27	29·46	30·67	31·91	33·18	34·47	35·78	37·12	6
7	38·48	39·87	41·28	42·71	44·17	45·66	47·17	48·70	7
8	50·27	51·84	53·45	55·08	56·74	58·42	60·13	61·86	8
9	63·62	65·39	67·20	69·02	70·88	72·75	74·66	76·58	9
10	78·54	80·51	82·51	84·54	86·59	88·66	90·76	92·88	10
11	95·03	97·20	99·40	101·6	103·8	106·1	108·4	110·7	11
12	113·1	115·4	117·8	120·2	122·7	125·1	127·6	130·1	12
13	132·7	135·2	137·8	140·5	143·1	145·8	148·4	151·2	13
14	153·9	156·6	159·4	162·2	165·1	167·9	170·8	173·7	14
15	176·7	179·6	182·6	185·6	188·6	191·7	194·8	197·9	15
16	201·1	204·2	207·3	210·5	213·8	217·0	220·3	223·6	16
17	227·0	230·3	233·7	237·1	240·5	243·9	247·4	250·9	17
18	254·4	258·0	261·5	265·1	268·8	272·4	276·1	279·8	18
19	283·5	287·2	291·0	294·8	298·6	302·4	306·3	310·2	19
20	314·1	318·1	322·0	326·0	330·0	334·1	338·1	342·2	20
21	346·4	350·4	354·6	358·8	363·0	367·2	371·5	375·8	21
22	380·1	384·4	388·8	393·2	397·6	402·0	406·4	410·9	22
23	415·5	420·0	424·5	429·1	433·7	438·3	443·0	447·6	23
24	452·4	457·1	461·8	466·6	471·4	476·2	481·1	485·9	24
25	490·9	495·7	500·7	505·7	510·7	515·7	520·7	525·8	25
26	530·9	536·0	541·1	546·3	551·5	556·7	562·0	567·2	26
27	572·6	577·8	583·2	588·5	593·9	599·3	604·8	610·2	27
28	615·8	621·2	626·7	632·3	637·9	643·5	649·1	654·8	28
29	660·5	666·2	671·9	677·7	683·4	689·2	695·1	700·9	29
30	706·9	712·7	718·6	724·6	730·6	736·6	742·6	748·6	30

AREAS OF CIRCLES, ADVANCING BY 8THS—*continued.*

Diam.	Areas.							
	·0	·⅛	·¼	·⅜	·½	·⅝	·¾	·⅞
31	754·8	760·9	767·0	773·1	779·3	785·5	791·7	798·0
32	804·2	810·5	816·9	823·2	829·6	836·0	842·4	848·8
33	855·3	861·8	868·3	874·8	881·4	888·0	894·6	901·3
34	907·9	914·6	921·3	928·1	934·8	941·6	948·4	955·3
35	962·1	969·0	975·9	982·8	989·8	996·8	1003·8	1010·8
36	1017·9	1025·0	1032·1	1039·2	1046·4	1053·5	1060·7	1068·0
37	1075·2	1082·5	1089·8	1097·1	1104·5	1111·8	1119·2	1126·7
38	1134·1	1141·6	1149·1	1156·6	1164·2	1171·7	1179·3	1186·9
39	1194·6	1202·3	1210·0	1217·7	1225·4	1233·2	1241·0	1248·8
40	1256·6	1264·5	1272·4	1280·3	1288·3	1296·2	1304·2	1312·2
41	1320·3	1328·3	1336·4	1344·5	1352·7	1360·8	1369·0	1377·2
42	1385·4	1393·7	1402·0	1410·3	1418·6	1427·0	1435·4	1443·8
43	1452·2	1460·7	1469·1	1477·6	1486·2	1494·7	1503·3	1511·9
44	1520·5	1529·2	1537·9	1546·6	1555·3	1564·0	1572·8	1581·6
45	1590·4	1599·3	1608·2	1617·0	1626·0	1634·9	1643·9	1652·9
46	1661·9	1671·0	1680·0	1689·1	1698·2	1707·4	1716·5	1725·7
47	1734·9	1744·2	1753·5	1762·7	1772·1	1781·4	1790·8	1800·1
48	1809·6	1819·0	1828·5	1837·9	1847·5	1857·0	1866·6	1876·1
49	1885·7	1895·4	1905·0	1914·7	1924·4	1934·2	1943·9	1953·7
50	1963·5	1973·3	1983·2	1993·1	2003·0	2012·9	2022·8	2032·8
51	2042·8	2052·9	2062·9	2073·0	2083·1	2093·2	2103·4	2113·5
52	2123·7	2133·9	2144·2	2154·5	2164·8	2175·1	2185·4	2195·8
53	2206·2	2216·6	2227·1	2237·5	2248·0	2258·5	2269·1	2279·6
54	2290·2	2300·8	2311·5	2322·1	2332·8	2343·5	2354·3	2365·0
55	2375·8	2386·6	2397·5	2408·3	2419·2	2430·2	2441·1	2452·0
56	2463·0	2474·0	2485·1	2496·1	2507·2	2518·3	2529·4	2540·6
57	2551·8	2563·0	2574·2	2585·5	2596·7	2608·0	2619·4	2630·7
58	2642·1	2653·5	2664·9	2676·4	2687·8	2699·3	2710·9	2722·4
59	2734·0	2745·6	2757·2	2768·8	2780·5	2792·2	2803·9	2815·7
60	2827·4	2839·2	2851·1	2862·9	2874·8	2886·7	2898·6	2910·5
61	2922·5	2934·5	2946·5	2958·5	2970·6	2982·7	2994·8	3006·9
62	3019·1	3031·3	3043·5	3055·7	3068·0	3080·3	3092·6	3104·9
63	3117·3	3129·6	3142·0	3154·5	3166·9	3179·4	3191·9	3204·4
64	3217·0	3229·6	3242·2	3254·8	3267·5	3280·1	3292·8	3305·6
65	3318·3	3331·1	3343·9	3356·7	3369·6	3382·4	3395·3	3408·3

AREAS OF CIRCLES, ADVANCING BY 8THS—*continued.*

Diam.	Areas.							
	·0	·⅛	·¼	·⅜	·½	·⅝	·¾	·⅞
66	3421·2	3434·2	3447·2	3460·2	3473·2	3486·3	3499·4	3512·5
67	3525·7	3538·8	3552·0	3565·2	3578·5	3591·7	3605·0	3618·4
68	3631·7	3645·1	3658·4	3671·9	3685·3	3698·8	3712·2	3725·8
69	3739·3	3752·8	3766·4	3780·0	3793·7	3807·3	3821·0	3834·7
70	3848·5	3862·2	3876·0	3889·8	3903·6	3917·5	3931·4	3945·3
71	3959·2	3973·2	3987·1	4001·1	4015·2	4029·2	4043·3	4057·4
72	4071·5	4085·7	4099·8	4114·0	4128·3	4142·5	4156·8	4171·1
73	4185·4	4199·7	4214·1	4228·5	4242·9	4257·4	4271·8	4286·3
74	4300·9	4315·4	4330·0	4344·6	4359·2	4373·8	4388·5	4403·2
75	4417·9	4432·6	4447·4	4462·2	4477·0	4491·8	4506·7	4521·6
76	4536·5	4551·4	4566·4	4581·3	4596·4	4611·4	4626·4	4641·5
77	4656·6	4671·8	4686·9	4702·1	4717·3	4732·5	4747·8	4763·1
78	4778·4	4793·7	4809·1	4824·4	4839·8	4855·3	4870·7	4886·2
79	4901·7	4917·2	4932·8	4948·3	4963·9	4979·5	4995·2	5010·9
80	5026·6	5042·3	5058·0	5073·8	5089·6	5105·4	5121·2	5137·1
81	5153·0	5168·9	5184·9	5200·8	5216·8	5232·8	5248·9	5264·9
82	5281·0	5297·1	5313·3	5329·4	5345·6	5361·8	5378·1	5394·3
83	5410·6	5426·9	5443·3	5459·6	5476·0	5492·4	5508·8	5525·3
84	5541·8	5558·3	5574·8	5591·4	5608·0	5624·6	5641·2	5657·8
85	5674·5	5691·2	5707·9	5724·7	5741·5	5758·3	5775·1	5791·9
86	5808·8	5825·7	5842·6	5859·6	5876·6	5893·6	5910·6	5927·6
87	5944·7	5961·8	5978·9	5996·1	6013·2	6030·4	6047·6	6064·9
88	6082·1	6099·4	6116·7	6134·1	6151·4	6169·8	6186·3	6203·7
89	6221·2	6238·6	6256·2	6273·7	6291·3	6308·8	6326·4	6344·1
90	6361·7	6379·4	6397·1	6414·9	6432·6	6450·4	6468·2	6486·0
91	6503·9	6521·8	6539·7	6557·6	6575·6	6593·5	6611·5	6629·6
92	6647·6	6665·7	6683·8	6701·9	6720·1	6738·3	6756·5	6774·7
93	6792·9	6811·2	6829·5	6847·8	6866·2	6884·5	6902·9	6921·3
94	6939·8	6958·3	6976·8	6995·3	7013·8	7032·4	7051·0	7069·6
95	7088·2	7106·9	7125·6	7144·3	7163·0	7181·8	7200·6	7219·4
96	7238·2	7257·1	7276·0	7294·9	7313·8	7332·8	7351·8	7370·8
97	7389·8	7408·9	7428·0	7447·1	7466·2	7485·4	7504·5	7523·8
98	7543·0	7562·2	7581·5	7600·8	7620·1	7639·5	7658·9	7678·3
99	7697·7	7717·2	7736·6	7756·1	7775·7	7795·2	7814·8	7834·4

Areas of Small Circles, advancing by decimals.

Diam.	Areas. ·000	·001	·002	·003	·004
·000	0	·0000008	·0000031	·0000071	·0000126
·010	·0000785	·0000950	·0001131	·0001327	·0001539
·020	·0003142	·0003464	·0003801	·0004155	·0004524
·030	·0007069	·0007548	·0008043	·0008553	·0009079
·040	·0012566	·0013203	·0013854	·0014522	·0015205
·050	·0019635	·0020428	·0021237	·0022062	·0022902
·060	·0028274	·0029225	·0030191	·0031172	·0032170
·070	·0038484	·0039592	·0040715	·0041854	·0043008
·080	·0050276	·0051530	·0052810	·0054106	·0055418
·090	·0063617	·0065039	·0066476	·0067929	·0069398

Diam.	·005	·006	·007	·008	·009
·000	·0000196	·0000283	·0000385	·0000503	·0000636
·010	·0001767	·0002016	·0002270	·0002565	·0002835
·020	·0004909	·0005309	·0005726	·0006158	·0006605
·030	·0009621	·0010179	·0010752	·0011341	·0011946
·040	·0015904	·0016619	·0017349	·0018096	·0018857
·050	·0023758	·0024630	·0025517	·0026421	·0027340
·060	·0033183	·0034212	·0035257	·0036317	·0037393
·070	·0044179	·0045365	·0046566	·0047784	·0049017
·080	·0056745	·0058088	·0059447	·0060821	·0062211
·090	·0070882	·0072382	·0073898	·0075430	·0076977

Areas of Small Circles.

Diam.	·00	·01	·02	·03	·04	·05	·06	·07	·08	·09
·0	·0	·000078	·00031	·0007	·00125	·00196	·00283	·00385	·00503	·00636
·1	·0078	·0095	·0113	·0133	·0154	·0177	·0201	·0227	·0255	·0283
·2	·0314	·03464	·038	·0415	·0452	·0491	·0531	·0572	·0616	·066
·3	·0706	·0755	·0804	·0855	·0908	·0962	·1018	·1075	·1134	·1195
·4	·1256	·132	·1385	·1452	·1520	·1590	·1662	·1735	·181	·1886
·5	·1963	·2043	·2124	·2206	·2290	·2376	·2463	·2552	·2642	·2734
·6	·2827	·2922	·3014	·3117	·3217	·3318	·3421	·3526	·3632	·3739
·7	·3848	·3959	·4071	·4185	·4301	·4418	·4536	·4657	·4778	·4902
·8	·5026	·5153	·5281	·5411	·5542	·5674	·5809	·5945	·6082	·6221
·9	·6362	·6504	·6648	·6793	·694	·7088	·7238	·739	·7543	·7693

AREAS OF CIRCLES, ADVANCING BY 10THS.

Diam.	Areas.										Diam.
	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	
0	·0	·0078	·0314	·0706	·1256	·1963	·2827	·3848	·5026	·6361	0
1	·7854	·9503	1·1309	1·3273	1·5393	1·7671	2·0106	2·2698	2·5446	2·8352	1
2	3·1416	3·4636	3·8013	4·1547	4·5239	4·9087	5·3093	5·7255	6·1575	6·6052	2
3	7·0686	7·5476	8·0424	8·5530	9·0792	9·6211	10·1787	10·7521	11·3411	11·9459	3
4	12·5664	13·2025	13·8544	14·5220	15·2053	15·9043	16·6190	17·3494	18·0951	18·8574	4
5	19·6350	20·4282	21·2372	22·0618	22·9022	23·7583	24·6301	25·5176	26·4208	27·3397	5
6	28·2744	29·2247	30·1907	31·1725	32·1699	33·1831	34·2120	35·2566	36·3168	37·3928	6
7	38·4846	39·5920	40·7151	41·8539	43·0085	44·1787	45·3647	46·5663	47·7837	49·0168	7
8	50·2656	51·5300	52·8102	54·1062	55·4178	56·7451	58·0881	59·4469	60·8213	62·2115	8
9	63·6174	65·0389	66·4762	67·9292	69·3979	70·8823	72·3824	73·8982	75·4298	76·9770	9
10	78·5400	80·1186	81·7130	83·3230	84·9488	86·5903	88·2475	89·9204	91·6090	93·3133	10
11	95·0334	96·7691	98·5205	100·287	102·070	103·869	105·683	107·513	109·359	111·220	11
12	113·097	114·990	116·898	118·823	120·763	122·718	124·690	126·677	128·679	130·698	12
13	132·732	134·782	136·848	138·929	141·026	143·139	145·267	147·411	149·571	151·747	13
14	153·938	156·145	158·368	160·606	162·860	165·130	167·415	169·717	172·034	174·366	14
15	176·715	179·079	181·458	183·854	186·265	188·692	191·134	193·593	196·067	198·556	15
16	201·062	203·583	206·120	208·672	211·241	213·825	216·424	219·040	221·671	224·318	16
17	226·980	229·658	232·352	235·062	237·787	240·528	243·285	246·057	248·846	251·650	17
18	254·469	257·304	260·155	263·022	265·905	268·803	271·716	274·646	277·591	280·552	18
19	283·529	286·521	289·529	292·553	295·593	298·648	301·719	304·805	307·908	311·026	19
20	314·160	317·309	320·474	323·655	326·852	330·064	333·292	336·536	339·795	343·070	20
	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	

Areas of Circles, advancing by 10ths—*continued.*

Diam.	Areas.										Diam.
	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	
21	346·361	349·667	352·990	356·328	359·681	363·051	366·436	369·837	373·253	376·685	21
22	380·133	383·597	387·076	390·571	394·082	397·608	401·150	404·708	408·282	411·871	22
23	415·476	419·097	422·733	426·385	430·053	433·737	437·436	441·151	444·881	448·628	23
24	452·390	456·168	459·961	463·770	467·595	471·436	475·292	479·164	483·052	486·955	24
25	490·875	494·809	498·760	502·726	506·708	510·706	514·719	518·748	522·793	526·854	25
26	530·930	535·022	539·129	543·253	547·392	551·547	555·717	559·903	564·105	568·323	26
27	572·556	576·805	581·070	585·350	589·646	593·958	598·286	602·629	606·988	611·363	27
28	615·753	620·159	624·581	629·019	633·472	637·941	642·425	646·926	651·442	655·973	28
29	660·521	665·084	669·663	674·258	678·868	683·494	688·136	692·793	697·466	702·155	29
30	706·860	711·580	716·316	721·067	725·835	730·618	735·417	740·231	745·061	749·907	30
31	754·769	759·646	764·539	769·448	774·372	779·313	784·268	789·240	794·227	799·230	31
32	804·249	809·284	814·334	819·399	824·481	829·578	834·691	839·820	844·964	850·124	32
33	855·300	860·492	865·699	870·922	876·160	881·415	886·685	891·970	897·272	902·589	33
34	907·922	913·270	918·635	924·011	929·410	934·822	940·249	945·692	951·150	956·625	34
35	962·115	967·620	973·142	978·679	984·231	989·800	995·384	1000·98	1006·60	1012·23	35
36	1017·87	1023·54	1029·21	1034·91	1040·62	1046·34	1052·09	1057·84	1063·62	1069·40	36
37	1075·21	1081·03	1086·86	1092·71	1098·58	1104·46	1110·36	1116·28	1122·21	1128·15	37
38	1134·11	1140·09	1146·08	1152·09	1158·11	1164·15	1170·21	1176·28	1182·37	1188·47	38
39	1194·59	1200·72	1206·87	1213·04	1219·22	1225·42	1231·63	1237·86	1244·10	1250·36	39
40	1256·64	1262·93	1269·23	1275·56	1281·89	1288·25	1294·62	1301·00	1307·40	1313·82	40
	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	

Areas of Circles, advancing by 10ths—*continued.*

Diam.	Areas. ·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	Diam.
41	1320·25	1326·70	1333·16	1339·64	1346·14	1352·65	1359·18	1365·72	1372·28	1378·85	41
42	1385·44	1392·05	1398·67	1405·30	1411·96	1418·62	1425·31	1432·01	1438·72	1445·45	42
43	1452·20	1458·96	1465·74	1472·53	1479·34	1486·17	1493·01	1499·87	1506·74	1513·62	43
44	1520·53	1527·45	1534·38	1541·33	1548·30	1555·28	1562·28	1569·29	1576·32	1583·37	44
45	1590·43	1597·51	1604·60	1611·71	1618·83	1625·97	1633·12	1640·30	1647·48	1654·68	45
46	1661·90	1669·13	1676·38	1683·65	1690·93	1698·23	1705·54	1712·87	1720·21	1727·57	46
47	1734·94	1742·33	1749·74	1757·16	1764·60	1772·05	1779·52	1787·01	1794·51	1802·02	47
48	1809·56	1817·10	1824·67	1832·25	1839·84	1847·45	1855·08	1862·72	1870·38	1878·05	48
49	1885·74	1893·45	1901·17	1908·90	1916·65	1924·42	1932·20	1940·00	1947·82	1955·65	49
50	1963·50	1971·36	1979·23	1987·13	1995·04	2002·96	2010·90	2018·86	2026·83	2634·82	50
51	2042·82	2050·84	2058·87	2066·92	2074·99	2083·07	2091·17	2099·28	2107·41	2115·56	51
52	2123·72	2131·89	2140·08	2148·29	2156·51	2164·75	2173·01	2181·28	2189·56	2197·87	52
53	2206·18	2214·52	2222·87	2231·23	2239·61	2248·01	2256·42	2264·85	2273·29	2281·75	53
54	2290·22	2298·71	2307·22	2315·74	2324·28	2332·83	2341·40	2349·98	2358·58	2367·20	54
55	2375·83	2384·48	2393·14	2401·82	2410·51	2419·22	2427·95	2436·69	2445·45	2454·22	55
56	2463·01	2471·81	2480·63	2489·47	2498·32	2507·19	2516·07	2524·97	2533·88	2542·81	56
57	2551·76	2560·72	2569·70	2578·69	2587·70	2596·72	2605·76	2614·12	2623·89	2632·98	57
58	2642·08	2651·20	2660·33	2669·48	2678·65	2687·83	2697·03	2706·24	2715·47	2724·71	58
59	2733·97	2743·25	2752·54	2761·85	2771·17	2780·51	2789·86	2799·23	2808·62	2818·02	59
60	2827·44	2836·87	2846·32	2855·78	2865·26	2874·76	2884·26	2893·79	2903·34	2912·89	60
	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	

AREAS OF CIRCLES, ADVANCING BY 10THS—*continued.*

Diam.	Areas.										Diam.
	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	
61	2922·47	2932·06	2941·66	2951·28	2960·92	2970·57	2980·24	2989·93	2999·63	3009·34	61
62	3019·07	3028·82	3038·58	3048·36	3058·15	3067·96	3077·79	3087·63	3097·49	3107·36	62
63	3117·25	3127·15	3137·07	3147·01	3156·96	3166·92	3176·91	3186·90	3196·92	3206·95	63
64	3216·99	3227·05	3237·13	3247·22	3257·33	3267·46	3277·59	3287·75	3297·92	3308·11	64
65	3318·31	3328·53	3338·76	3349·01	3359·28	3369·56	3379·85	3390·17	3400·49	3410·84	65
66	3421·20	3431·57	3441·96	3452·37	3462·79	3473·23	3483·68	3494·16	3504·64	3515·14	66
67	3525·66	3536·19	3546·74	3557·30	3567·88	3578·47	3589·08	3599·71	3610·35	3621·01	67
68	3631·68	3642·37	3653·08	3663·80	3674·54	3685·29	3696·06	3706·84	3717·64	3728·45	68
69	3739·28	3750·13	3760·99	3771·87	3782·76	3793·67	3804·60	3815·54	3826·50	3837·47	69
70	3848·46	3859·46	3870·48	3881·51	3892·56	3903·63	3914·71	3925·81	3936·92	3948·05	70
71	3959·20	3970·36	3981·53	3992·73	4003·93	4015·16	4026·40	4037·65	4048·92	4060·21	71
72	4071·51	4082·83	4094·16	4105·51	4116·87	4128·25	4139·65	4151·06	4162·49	4173·93	72
73	4185·39	4196·87	4208·36	4219·86	4231·38	4242·92	4254·48	4266·04	4277·63	4289·23	73
74	4300·85	4312·48	4324·12	4335·79	4347·47	4359·16	4370·87	4382·60	4394·34	4406·10	74
75	4417·87	4429·66	4441·46	4453·28	4465·12	4476·97	4488·84	4500·72	4512·62	4524·54	75
76	4536·47	4548·41	4560·37	4572·35	4584·35	4596·35	4608·38	4620·42	4632·47	4644·54	76
77	4656·63	4668·73	4680·85	4692·99	4705·14	4717·30	4729·49	4741·68	4753·96	4766·12	77
78	4778·37	4790·63	4802·90	4815·20	4827·50	4839·83	4852·16	4864·52	4876·89	4889·27	78
79	4901·68	4914·09	4926·53	4938·98	4951·44	4963·92	4976·42	4988·93	5001·45	5014·00	79
80	5026·56	5039·13	5051·72	5064·32	5076·95	5089·58	5102·24	5114·90	5127·59	5140·29	80
	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	

Areas of Circles, advancing by 10ths—*continued.*

Diam.	Areas.										Diam.
	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	
81	5153·00	5165·74	5178·48	5191·25	5204·02	5216·82	5229·63	5242·45	5255·29	5268·15	81
82	5281·02	5293·91	5306·82	5319·74	5332·67	5345·62	5358·59	5371·57	5384·57	5397·59	82
83	5410·62	5423·66	5436·72	5449·80	5462·89	5476·00	5489·12	5502·26	5515·42	5528·59	83
84	5541·78	5554·98	5568·20	5581·43	5594·68	5607·95	5621·23	5634·53	5647·84	5661·17	84
85	5674·51	5687·87	5701·25	5714·64	5728·04	5741·47	5754·90	5768·36	5781·83	5795·31	85
86	5808·81	5822·33	5835·86	5849·41	5862·97	5876·55	5890·15	5903·76	5917·39	5931·03	86
87	5944·69	5958·36	5972·05	5985·76	5999·48	6013·21	6026·97	6040·73	6054·52	6068·32	87
88	6082·13	6095·96	6109·81	6123·67	6137·55	6151·44	6165·35	6179·28	6193·22	6207·18	88
89	6221·15	6235·14	6249·14	6263·16	6277·19	6291·20	6305·31	6319·39	6333·49	6347·61	89
90	6361·74	6375·88	6390·04	6404·22	6418·41	6432·62	6446·84	6461·08	6475·34	6489·61	90
91	6503·89	6518·19	6532·51	6546·85	6561·20	6575·56	6589·94	6604·34	6618·75	6633·18	91
92	6647·62	6662·08	6676·55	6691·05	6705·55	6720·07	6734·61	6749·16	6763·73	6778·32	92
93	6792·92	6807·54	6822·17	6836·82	6851·48	6866·16	6880·85	6895·56	6910·29	6925·03	93
94	6939·79	6954·56	6969·35	6984·16	6998·98	7013·81	7028·67	7043·53	7058·42	7073·32	94
95	7088·23	7103·16	7118·11	7133·07	7148·05	7163·04	7178·05	7193·07	7208·11	7223·17	95
96	7238·24	7253·33	7268·43	7283·55	7298·69	7313·84	7329·00	7344·18	7359·38	7374·59	96
97	7389·82	7405·07	7420·33	7435·60	7450·90	7466·20	7481·53	7496·87	7512·22	7527·59	97
98	7542·98	7558·38	7573·80	7589·23	7604·68	7620·14	7635·62	7651·19	7666·63	7682·16	98
99	7697·70	7713·26	7728·83	7744·42	7760·03	7775·65	7791·29	7806·94	7822·61	7838·29	99
100	7854·00	7869·71	7885·44	7901·19	7916·95	7932·73	7948·53	7964·34	7980·16	7996·00	100
	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	

Circumferences of Circles, advancing by 8ths.

Diam.	Circumferences.								Diam.
	·0	·⅛	·¼	·⅜	·½	·⅝	·¾	·⅞	
0	·0	·3927	·7854	1·178	1·570	1·963	2·356	2·748	0
1	3·141	3·534	3·927	4·319	4·712	5·105	5·497	5·890	1
2	6·283	6·675	7·068	7·461	7·854	8·246	8·639	9·032	2
3	9·424	9·817	10·21	10·60	10·99	11·38	11·78	12·17	3
4	12·56	12·95	13·35	13·74	14·13	14·52	14·92	15·31	4
5	15·70	16·10	16·49	16·88	17·27	17·67	18·06	18·45	5
6	18·84	19·24	19·63	20·02	20·42	20·81	21·20	21·59	6
7	21·99	22·38	22·77	23·16	23·56	23·95	24·34	24·74	7
8	25·13	25·52	25·91	26·31	26·70	27·09	27·48	27·88	8
9	28·27	28·66	29·05	29·45	29·84	30·23	30·63	31·02	9
10	31·41	31·80	32·20	32·59	32·98	33·37	33·77	34·16	10
11	34·55	34·95	35·34	35·73	36·12	36·52	36·91	37·30	11
12	37·69	38·09	38·48	38·87	39·27	39·66	40·05	40·44	12
13	40·84	41·23	41·62	42·01	42·41	42·80	43·19	43·58	13
14	43·98	44·37	44·76	45·16	45·55	45·94	46·33	46·73	14
15	47·12	47·51	47·90	48·30	48·69	49·08	49·48	49·87	15
16	50·26	50·65	51·05	51·44	51·83	52·22	52·62	53·01	16
17	53·40	53·79	54·19	54·58	54·97	55·37	55·76	56·15	17
18	56·54	56·94	57·33	57·72	58·11	58·51	58·90	59·29	18
19	59·69	60·08	60·47	60·86	61·26	61·65	62·04	62·43	19
20	62·83	63·22	63·61	64·01	64·40	64·79	65·18	65·58	20
21	65·97	66·36	66·75	67·15	67·54	67·93	68·32	68·72	21
22	69·11	69·50	69·90	70·29	70·68	71·07	71·47	71·86	22
23	72·25	72·64	73·04	73·43	73·82	74·22	74·61	75·00	23
24	75·39	75·79	76·18	76·57	76·96	77·36	77·75	78·14	24
25	78·54	78·93	79·32	79·71	80·10	80·50	80·89	81·28	25
26	81·68	82·07	82·46	82·85	83·25	83·64	84·03	84·43	26
27	84·82	85·21	85·60	86·00	86·39	86·78	87·17	87·57	27
28	87·96	88·35	88·75	89·14	89·53	89·92	90·32	90·71	28
29	91·10	91·49	91·89	92·28	92·67	93·06	93·46	93·85	29
30	94·24	94·64	95·03	95·42	95·81	96·21	96·60	96·99	30

CIRCUMFERENCES OF CIRCLES, ADVANCING BY 8THS—*cont.*

Diam.	Circumferences.								Diam.
	·0	·$\frac{1}{8}$	·$\frac{1}{4}$	·$\frac{3}{8}$	·$\frac{1}{2}$	·$\frac{5}{8}$	·$\frac{3}{4}$	·$\frac{7}{8}$	
31	97·4	97·8	98·2	98·6	99·0	99·4	99·7	100·1	31
32	100·5	100·9	101·3	101·7	102·1	102·5	102·9	103·3	32
33	103·7	104·1	104·5	104·9	105·2	105·6	106·0	106·4	33
34	106·8	107·2	107·6	108·0	108·4	108·8	109·2	109·6	34
35	110·0	110·3	110·7	111·1	111·5	111·9	112·3	112·7	35
36	113·1	113·5	113·9	114·3	114·7	115·1	115·5	115·8	36
37	116·2	116·6	117·0	117·4	117·8	118·2	118·6	119·0	37
38	119·4	119·8	120·2	120·6	121·0	121·3	121·7	122·1	38
39	122·5	122·9	123·3	123·7	124·1	124·5	124·9	125·3	39
40	125·7	126·1	126·4	126·8	127·2	127·6	128·0	128·4	40
41	128·8	129·2	129·6	130·0	130·4	130·8	131·2	131·6	41
42	131·9	132·3	132·7	133·1	133·5	133·9	134·3	134·7	42
43	135·1	135·5	135·9	136·3	136·7	137·1	137·4	137·8	43
44	138·2	138·6	139·0	139·4	139·8	140·2	140·6	141·0	44
45	141·4	141·8	142·2	142·6	142·9	143·3	143·7	144·1	45
46	144·5	144·9	145·3	145·7	146·1	146·5	146·9	147·3	46
47	147·7	148·0	148·4	148·8	149·2	149·6	150·0	150·4	47
48	150·8	151·2	151·6	152·0	152·4	152·8	153·2	153·5	48
49	153·9	154·3	154·7	155·1	155·5	155·9	156·3	156·7	49
50	157·1	157·5	157·9	158·3	158·7	159·0	159·4	159·8	50
51	160·2	160·6	161·0	161·4	161·8	162·2	162·6	163·0	51
52	163·4	163·8	164·1	164·5	164·9	165·3	165·7	166·1	52
53	166·5	166·9	167·3	167·7	168·1	168·5	168·9	169·3	53
54	169·6	170·0	170·4	170·8	171·2	171·6	172·0	172·4	54
55	172·8	173·2	173·6	174·0	174·4	174·8	175·1	175·5	55
56	175·9	176·3	176·7	177·1	177·5	177·9	178·3	178·7	56
57	179·1	179·5	179·9	180·2	180·6	181·0	181·4	181·8	57
58	182·2	182·6	183·0	183·4	183·8	184·2	184·6	185·0	58
59	185·4	185·7	186·1	186·5	186·9	187·3	187·7	188·1	59
60	188·5	188·9	189·3	189·7	190·1	190·5	190·9	191·2	60
61	191·6	192·0	192·4	192·8	193·2	193·6	194·0	194·4	61
62	194·8	195·2	195·6	196·0	196·4	196·7	197·1	197·5	62
63	197·9	198·3	198·7	199·1	199·5	199·9	200·3	200·7	63
64	201·1	201·5	201·8	202·2	202·6	203·0	203·4	203·8	64
65	204·2	204·6	205·0	205·4	205·8	206·2	206·6	207·0	65

CIRCUMFERENCES OF CIRCLES, ADVANCING BY 8THS—*cont.*

Diam.	Circumferences. ·0	·1/8	·1/4	·3/8	·1/2	·5/8	·3/4	·7/8	Diam.
66	207·3	207·7	208·1	208·5	208·9	209·3	209·7	210·1	66
67	210·5	210·9	211·3	211·7	212·1	212·5	212·8	213·2	67
68	213·6	214·0	214·4	214·8	215·2	215·6	216·0	216·4	68
69	216·8	217·2	217·6	217·9	218·3	218·7	219·1	219·5	69
70	219·9	220·3	220·7	221·1	221·5	221·9	222·3	222·7	70
71	223·1	223·4	223·8	224·2	224·6	225·0	225·4	225·8	71
72	226·2	226·6	227·0	227·4	227·8	228·2	228·6	228·9	72
73	229·3	229·7	230·1	230·5	230·9	231·3	231·7	232·1	73
74	232·5	232·9	233·3	233·7	234·0	234·4	234·8	235·2	74
75	235·6	236·0	236·4	236·8	237·2	237·6	238·0	238·4	75
76	238·8	239·2	239·5	239·9	240·3	240·7	241·1	241·5	76
77	241·9	242·3	242·7	243·1	243·5	243·9	244·3	244·7	77
78	245·0	245·4	245·8	246·2	246·6	247·0	247·4	247·8	78
79	248·2	248·6	249·0	249·4	249·8	250·1	250·5	250·9	79
80	251·3	251·7	252·1	252·5	252·9	253·3	253·7	254·1	80
81	254·5	254·9	255·3	255·6	256·0	256·4	256·8	257·2	81
82	257·6	258·0	258·4	258·8	259·2	259·6	260·0	260·4	82
83	260·8	261·1	261·5	261·9	262·3	262·7	263·1	263·5	83
84	263·9	264·3	264·7	265·1	265·5	265·9	266·3	266·6	84
85	267·0	267·4	267·8	268·2	268·6	269·0	269·4	269·8	85
86	270·2	270·6	271·0	271·4	271·7	272·1	272·5	272·9	86
87	273·3	273·7	274·1	274·5	274·9	275·3	275·7	276·1	87
88	276·5	276·9	277·2	277·6	278·0	278·4	278·8	279·2	88
89	279·6	280·0	280·4	280·8	281·2	281·6	282·0	282·4	89
90	282·7	283·1	283·5	283·9	284·3	284·7	285·1	285·5	90
91	285·9	286·3	286·7	287·1	287·5	287·8	288·2	288·6	91
92	289·0	289·4	289·8	290·2	290·6	291·0	291·4	291·8	92
93	292·2	292·6	293·0	293·3	293·7	294·1	294·5	294·9	93
94	295·3	295·7	296·1	296·5	296·9	297·3	297·7	298·1	94
95	298·5	298·8	299·2	299·6	300·0	300·4	300·8	301·2	95
96	301·6	302·0	302·4	302·8	303·2	303·6	303·9	304·3	96
97	304·7	305·1	305·5	305·9	306·3	306·7	307·1	307·5	97
98	307·9	308·3	308·7	309·1	309·4	309·8	310·2	310·6	98
99	311·0	311·4	311·8	312·2	312·6	313·0	313·4	313·8	99

CIRCUMFERENCES OF CIRCLES.

Diam.	Circumferences.										Diam.
	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	
0	·00	·31	·62	·94	1·25	1·57	1·88	2·19	2·51	2·82	0
1	3·14	3·45	3·77	4·08	4·39	4·71	5·02	5·34	5·65	5·96	1
2	6·28	6·59	6·91	7·22	7·53	7·85	8·16	8·48	8·79	9·11	2
3	9·42	9·74	10·05	10·36	10·68	10·99	11·30	11·62	11·93	12·25	3
4	12·56	12·88	13·19	13·50	13·82	14·13	14·45	14·76	15·08	15·39	4
5	15·70	16·02	16·33	16·65	16·96	17·27	17·59	17·90	18·22	18·53	5
6	18·84	19·16	19·47	19·79	20·10	20·42	20·73	21·04	21·36	21·67	6
7	21·99	22·30	22·61	22·93	23·24	23·56	23·87	24·19	24·50	24·81	7
8	25·13	25·44	25·76	26·07	26·38	26·70	27·01	27·33	27·64	27·96	8
9	28·27	28·58	28·90	29·21	29·53	29·84	30·15	30·47	30·78	31·10	9
10	31·41	31·73	32·04	32·35	32·67	32·98	33·30	33·61	33·92	34·24	10
11	34·55	34·87	35·18	35·50	35·81	36·12	36·44	36·75	37·07	37·38	11
12	37·69	38·01	38·32	38·64	38·95	39·27	39·58	39·89	40·21	40·52	12
13	40·84	41·15	41·46	41·78	42·09	42·41	42·72	43·03	43·35	43·66	13
14	43·98	44·29	44·61	44·92	45·23	45·55	45·86	46·18	46·49	46·80	14
15	47·12	47·43	47·75	48·06	48·38	48·69	49·00	49·32	49·63	49·95	15
16	50·26	50·57	50·89	51·20	51·52	51·83	52·15	52·46	52·78	53·09	16
17	53·40	53·72	54·03	54·35	54·65	54·97	55·29	55·60	55·92	56·23	17
18	56·54	56·86	57·17	57·49	57·80	58·11	58·43	58·74	59·06	59·37	18
19	59·69	60·00	60·31	60·63	60·94	61·26	61·57	61·88	62·20	62·51	19
20	62·83	63·14	63·46	63·77	64·08	64·40	64·71	65·03	65·34	65·65	20
21	65·97	66·28	66·60	66·91	67·22	67·54	67·85	68·17	68·48	68·80	21
22	69·11	69·42	69·74	70·05	70·37	70·68	71·00	71·31	71·62	71·94	22
23	72·25	72·57	72·88	73·19	73·51	73·82	74·14	74·45	74·76	75·08	23
24	75·39	75·71	76·02	76·34	76·65	76·96	77·28	77·59	77·91	78·22	24
25	78·54	78·85	79·16	79·48	79·79	80·11	80·42	80·73	81·05	81·36	25
26	81·68	81·99	82·30	82·62	82·93	83·25	83·56	83·88	84·19	84·50	26
27	84·82	85·13	85·45	85·76	86·07	86·39	86·70	87·02	87·33	87·65	27
28	87·96	88·27	88·59	88·90	89·22	89·53	89·84	90·16	90·47	90·79	28
29	91·10	91·42	91·73	92·04	92·36	92·67	92·99	93·30	93·61	93·93	29
30	94·24	94·56	94·87	95·19	95·50	95·81	96·13	96·44	96·76	97·07	30
31	97·38	97·70	98·01	98·33	98·64	98·96	99·27	99·58	99·90	100·2	31
32	100·5	100·8	101·1	101·4	101·7	102·1	102·4	102·7	103·0	103·3	32
33	103·6	103·9	104·3	104·6	104·9	105·2	105·5	105·8	106·1	106·5	33
34	106·8	107·1	107·4	107·7	108·0	108·3	108·6	109·0	109·3	109·6	34
35	109·9	110·2	110·5	110·8	111·2	111·5	111·8	112·1	112·4	112·7	35

CIRCUMFERENCES OF CIRCLES—*continued.*

Diam.	Circumferences.										Diam.
	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	
36	113·0	113·4	113·7	114·0	114·3	114·6	114·9	115·2	115·6	115·9	36
37	116·2	116·5	116·8	117·1	117·4	117·8	118·1	118·4	118·7	119·0	37
38	119·3	119·6	120·0	120·3	120·6	120·9	121·2	121·5	121·8	122·2	38
39	122·5	122·8	123·1	123·4	123·7	124·0	124·4	124·7	125·0	125·3	39
40	125·6	125·9	126·2	126·6	126·9	127·2	127·5	127·8	128·1	128·4	40
41	128·8	129·1	129·4	129·7	130·0	130·3	130·6	131·0	131·3	131·6	41
42	131·9	132·2	132·5	132·8	133·2	133·5	133·8	134·1	134·4	134·7	42
43	135·0	135·4	135·7	136·0	136·3	136·6	136·9	137·2	137·6	137·9	43
44	138·2	138·5	138·8	139·1	139·4	139·8	140·1	140·4	140·7	141·0	44
45	141·3	141·6	142·0	142·3	142·6	142·9	143·2	143·5	143·9	144·2	45
46	144·5	144·8	145·1	145·4	145·7	146·0	146·3	146·7	147·0	147·3	46
47	147·6	147·9	148·2	148·5	148·9	149·2	149·5	149·8	150·1	150·4	47
48	150·7	151·1	151·4	151·7	152·0	152·3	152·6	152·9	153·3	153·6	48
49	153·9	154·2	154·5	154·8	155·1	155·5	155·8	156·1	156·4	156·7	49
50	157·0	157·3	157·7	158·0	158·3	158·6	158·9	159·2	159·5	159·9	50
51	160·2	160·5	160·8	161·1	161·4	161·7	162·1	162·4	162·7	163·0	51
52	163·3	163·6	163·9	164·3	164·6	164·9	165·2	165·5	165·8	166·1	52
53	166·5	166·8	167·1	167·4	167·7	168·0	168·3	168·7	169·0	169·3	53
54	169·6	169·9	170·2	170·5	170·9	171·2	171·5	171·8	172·1	172·4	54
55	172·7	173·1	173·4	173·7	174·0	174·3	174·6	174·9	175·3	175·6	55
56	175·9	176·2	176·5	176·8	177·1	177·5	177·8	178·1	178·4	178·7	56
57	179·0	179·3	179·7	180·0	180·3	180·6	180·9	181·2	181·5	181·9	57
58	182·2	182·5	182·8	183·1	183·4	183·7	184·0	184·4	184·7	185·0	58
59	185·3	185·6	185·9	186·2	186·6	186·9	187·2	187·5	187·8	188·1	59
60	188·4	188·8	189·1	189·4	189·7	190·0	190·3	190·6	191·0	191·3	60
61	191·6	191·9	192·2	192·5	192·8	193·2	193·5	193·8	194·1	194·4	61
62	194·7	195·0	195·4	195·7	196·0	196·3	196·6	196·9	197·2	197·6	62
63	197·9	198·2	198·5	198·8	199·1	199·4	199·8	200·1	200·4	200·7	63
64	201·0	201·3	201·6	202·0	202·3	202·6	202·9	203·2	203·5	203·8	64
65	204·2	204·5	204·8	205·1	205·4	205·7	206·0	206·4	206·7	207·0	65
66	207·3	207·6	207·9	208·2	208·6	208·9	209·2	209·5	209·8	210·1	66
67	210·4	210·8	211·1	211·4	211·7	212·0	212·3	212·6	213·0	213·3	67
68	213·6	213·9	214·2	214·5	214·8	215·1	215·5	215·8	216·1	216·4	68
69	216·7	217·0	217·3	217·7	218·0	218·3	218·6	218·9	219·2	219·5	69
70	219·9	220·2	220·5	220·8	221·1	221·4	221·7	222·1	222·4	222·7	70

CIRCUMFERENCES OF CIRCLES—*continued.*

Diam.	Circumferences.										Diam.
	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	
71	223·0	223·3	223·6	223·9	224·3	224·6	224·9	225·2	225·5	225·8	71
72	226·1	226·5	226·8	227·1	227·4	227·7	228·0	228·3	228·7	229·0	72
73	229·3	229·6	229·9	230·2	230·5	230·9	231·2	231·5	231·8	232·1	73
74	232·4	232·7	233·1	233·4	233·7	234·0	234·3	234·6	234·9	235·3	74
75	235·6	235·9	236·2	236·5	236·8	237·1	237·5	237·8	238·1	238·4	75
76	238·7	239·0	239·3	239·7	240·0	240·3	240·6	240·9	241·2	241·5	76
77	241·9	242·2	242·5	242·8	243·1	243·4	243·7	244·1	244·4	244·7	77
78	245·0	245·3	245·6	245·9	246·3	246·6	246·9	247·2	247·5	247·8	78
79	248·1	248·5	248·8	249·1	249·4	249·7	250·0	250·3	250·6	251·0	79
80	251·3	251·6	251·9	252·2	252·5	252·8	253·2	253·5	253·8	254·1	80
81	254·4	254·7	255·0	255·4	255·7	256·0	256·3	256·6	256·9	257·2	81
82	257·6	257·9	258·2	258·5	258·8	259·1	259·4	259·8	260·1	260·4	82
83	260·7	261·0	261·3	261·6	262·0	262·3	262·6	262·9	263·2	263·5	83
84	263·8	264·2	264·5	264·8	265·1	265·4	265·7	266·0	266·4	266·7	84
85	267·0	267·3	267·6	267·9	268·2	268·6	268·9	269·2	269·5	269·8	85
86	270·1	270·4	270·8	271·1	271·4	271·7	272·0	272·3	272·6	273·0	86
87	273·3	273·6	273·9	274·2	274·5	274·8	275·2	275·5	275·8	276·1	87
88	276·4	276·7	277·0	277·4	277·7	278·0	278·3	278·6	278·9	279·2	88
89	279·6	279·9	280·2	280·5	280·8	281·1	281·4	281·8	282·1	282·4	89
90	282·7	283·0	283·3	283·6	284·0	284·3	284·6	284·9	285·2	285·5	90
91	285·8	286·1	286·5	286·8	287·1	287·4	287·7	288·0	288·3	288·7	91
92	289·0	289·3	289·6	289·9	290·2	290·5	290·9	291·2	291·5	291·8	92
93	292·1	292·4	292·7	293·1	293·4	293·7	294·0	294·3	294·6	294·9	93
94	295·3	295·6	295·9	296·2	296·5	296·8	297·1	297·5	297·8	298·1	94
95	298·4	298·7	299·0	299·3	299·7	300·0	300·3	300·6	300·9	301·2	95
96	301·5	301·9	302·2	302·5	302·8	303·1	303·4	303·7	304·1	304·4	96
97	304·7	305·0	305·3	305·6	305·9	306·3	306·6	306·9	307·2	307·5	97
98	307·8	308·1	308·5	308·8	309·1	309·4	309·7	310·0	310·3	310·7	98
99	311·0	311·3	311·6	311·9	312·2	312·5	312·9	313·2	313·5	313·8	99
100	314·1	314·4	314·7	315·1	315·4	315·7	316·0	316·3	316·6	316·9	100

LENGTH OF THE CIRCULAR ARC SUBTENDED BY ANY ANGLE, Radius being = 1·00.

Degrees.					
°	arc.	°	arc.	°	arc.
1	·0174533	31	·5410521	61	1·0646508
2	·0349066	32	·5585054	62	1·0821041
3	·0523599	33	·5759587	63	1·0995574
4	·0698132	34	·5934119	64	1·1170107
5	·0872665	35	·6108652	65	1·1344640
6	·1047198	36	·6283185	66	1·1519173
7	·1221730	37	·6457718	67	1·1693706
8	·1396263	38	·6632251	68	1·1868239
9	·1570796	39	·6806784	69	1·2042772
10	·1745329	40	·6981317	70	1·2217305
11	·1919862	41	·7155850	71	1·2391828
12	·2094395	42	·7330383	72	1·2566371
13	·2268928	43	·7504916	73	1·2740904
14	·2443461	44	·7679449	74	1·2915436
15	·2617994	45	·7853982	75	1·3089969
16	·2792527	46	·8028515	76	1·3264502
17	·2967060	47	·8203047	77	1·3439035
18	·3141593	48	·8377580	78	1·3613568
19	·3316126	49	·8552113	79	1·3788101
20	·3490659	50	·8726646	80	1·3962634
21	·3665191	51	·8901179	81	1·4137167
22	·3839724	52	·9075712	82	1·4311700
23	·4014257	53	·9250245	83	1·4486233
24	·4188790	54	·9424778	84	1·4660766
25	·4363323	55	·9599311	85	1·4835299
26	·4537856	56	·9773844	86	1·5009832
27	·4712389	57	·9948377	87	1·5184364
28	·4886922	58	1·0122910	88	1·5358897
29	·5061455	59	1·0297443	89	1·5533430
30	·5235988	60	1·0471976	90	1·5707963

Length of the Circular Arc—*continued.*

Minutes.						Seconds.					
′	·00	′	·0	′	·0	″	·000	″	·000	″	·000
1	02909	21	061087	41	119264	1	0048	21	1018	41	1988
2	05818	22	063995	42	122173	2	0097	22	1067	42	2036
3	08727	23	066904	43	125082	3	0145	23	1115	43	2085
4	11636	24	069813	44	127991	4	0194	24	1164	44	2133
5	14544	25	072722	45	130900	5	0242	25	1212	45	2182
6	17453	26	075631	46	133809	6	0291	26	1261	46	2230
7	20362	27	078540	47	136717	7	0339	27	1309	47	2279
8	23271	28	081449	48	139626	8	0388	28	1357	48	2327
9	26180	29	084358	49	142535	9	0436	29	1406	49	2376
10	29089	30	087266	50	145444	10	0485	30	1454	50	2424
11	31998	31	090175	51	148353	11	0533	31	1503	51	2473
12	34907	32	093084	52	151262	12	0582	32	1551	52	2521
13	37815	33	095993	53	154171	13	0630	33	1599	53	2570
14	40724	34	098902	54	157080	14	0679	34	1648	54	2618
15	43633	35	101811	55	159989	15	0727	35	1697	55	2666
16	46542	36	104720	56	162897	16	0776	36	1745	56	2715
17	49451	37	107629	57	165806	17	0824	37	1794	57	2763
18	52360	38	110538	58	168715	18	0873	38	1842	58	2812
19	55269	39	113446	59	171624	19	0921	39	1891	59	2860
20	58178	40	116355	60	174533	20	0970	40	1939	60	2909

Length of Circular Arcs. (E. Donn.)

Versin. / chord.	0	·01	·02	·03	·04	·05	·06	·07	·08	·09
	·000	·000	·00	·00	·00	·00	·0	·0	·0	·0
0	0	267	11	24	43	67	096	130	170	215
·001	003	323	12	26	45	69	099	134	174	219
·002	011	384	13	27	47	72	102	138	178	224
·003	024	451	14	29	49	75	106	142	183	229
·004	043	523	15	31	52	78	109	145	187	234
·005	067	600	17	33	54	80	112	149	192	239
·006	096	683	18	35	56	83	116	153	196	244
·007	131	771	19	36	59	86	119	157	201	249
·008	171	864	21	38	61	89	123	161	205	254
·009	216	963	22	41	64	93	126	166	210	259

Approximate Rule for Length of Arc L.

$C =$ Chord of Arc; $c =$ Chord of $\frac{1}{2}$ Arc.
$L = \frac{1}{3}(8c - C)$.

LENGTH OF CIRCULAR ARCS.

Table of difference between the chord and the arc; chord being = 1·00. To find the length of any arc, divide the versed sine by the chord, and find the tabular No. (diff.) due to the result; then Length of arc = chord × (1 + diff.).

Vers. / Chord.	·000	·001	·002	·003	·004	·005	·006	·007	·008	·009
	diff.	diff.	diff.	diff.	diff.	diff.	diff.	diff.	diff.	diff.
·100	·0265	·0270	·0275	·0281	·0286	·0291	·0297	·0303	·0308	·0314
·110	·0320	·0325	·0331	·0337	·0343	·0349	·0355	·0361	·0367	·0373
·120	·0380	·0386	·0392	·0399	·0405	·0412	·0418	·0425	·0431	·0438
·130	·0445	·0451	·0458	·0465	·0472	·0479	·0486	·0493	·0500	·0507
·140	·0515	·0522	·0530	·0537	·0544	·0552	·0559	·0567	·0574	·0582
·150	·0590	·0597	·0605	·0613	·0621	·0629	·0637	·0645	·0653	·0661
·160	·0669	·0677	·0686	·0694	·0702	·0711	·0719	·0728	·0736	·0745
·170	·0754	·0762	·0771	·0780	·0789	·0798	·0807	·0816	·0825	·0834
·180	·0843	·0852	·0861	·0870	·0880	·0889	·0898	·0908	·0917	·0927
·190	·0936	·0946	·0956	·0965	·0975	·0985	·0995	·1005	·1015	·1025
·200	·1035	·1045	·1055	·1065	·1075	·1085	·1096	·1106	·1116	·1127
·210	·1137	·1148	·1158	·1169	·1180	·1190	·1201	·1212	·1222	·1233
·220	·1244	·1255	·1266	·1277	·1288	·1300	·1311	·1322	·1333	·1344
·230	·1356	·1367	·1379	·1390	·1402	·1414	·1425	·1436	·1448	·1460
·240	·1471	·1483	·1495	·1507	·1519	·1531	·1543	·1555	·1567	·1579
·250	·1591	·1603	·1616	·1628	·1640	·1653	·1665	·1677	·1690	·1702
·260	·1715	·1727	·1740	·1753	·1765	·1778	·1791	·1804	·1816	·1829
·270	·1843	·1856	·1869	·1882	·1895	·1908	·1921	·1934	·1948	·1961
·280	·1974	·1988	·2001	·2015	·2028	·2042	·2056	·2070	·2083	·2097
·290	·2111	·2124	·2138	·2152	·2166	·2179	·2193	·2206	·2220	·2235
·300	·2249	·2263	·2278	·2292	·2306	·2320	·2335	·2349	·2364	·2378
·310	·2392	·2407	·2422	·2436	·2451	·2465	·2480	·2495	·2509	·2524
·320	·2539	·2554	·2569	·2584	·2599	·2614	·2629	·2644	·2659	·2674
·330	·2689	·2704	·2720	·2735	·2750	·2766	·2781	·2796	·2812	·2827
·340	·2843	·2858	·2874	·2889	·2905	·2921	·2937	·2952	·2968	·2984
·350	·3000	·3016	·3031	·3047	·3063	·3079	·3095	·3111	·3128	·3144
·360	·3160	·3176	·3192	·3209	·3225	·3241	·3258	·3274	·3290	·3307
·370	·3323	·3340	·3356	·3373	·3390	·3406	·3423	·3440	·3456	·3473
·380	·3490	·3507	·3524	·3541	·3557	·3574	·3591	·3608	·3625	·3642
·390	·3660	·3677	·3694	·3711	·3728	·3745	·3763	·3780	·3797	·3815
·400	·3832	·3850	·3867	·3885	·3902	·3920	·3937	·3955	·3972	·3990
·410	·4008	·4025	·4043	·4061	·4079	·4097	·4114	·4132	·4150	·4168
·420	·4186	·4204	·4222	·4240	·4258	·4276	·4294	·4313	·4331	·4349
·430	·4367	·4386	·4404	·4422	·4440	·4459	·4477	·4496	·4514	·4533
·440	·4551	·4570	·4588	·4607	·4625	·4644	·4663	·4681	·4700	·4719
·450	·4738	·4756	·4775	·4794	·4813	·4832	·4851	·4870	·4889	·4908
·460	·4927	·4946	·4965	·4984	·5003	·5022	·5042	·5061	·5080	·5099
·470	·5118	·5138	·5157	·5176	·5196	·5215	·5235	·5254	·5274	·5293
·480	·5313	·5332	·5352	·5371	·5391	·5411	·5430	·5450	·5470	·5489
·490	·5509	·5529	·5548	·5568	·5588	·5608	·5628	·5648	·5668	·5688
·500	·5708	—	—	—	—	—	—	—	—	—

Contents of Spheres.

Diam.	·0	0·1	0·2	0·3	0·4	0·5	0·6	0·7	0·8	0·9	Diam.
0	..	·000523	·004189	·014137	·033510	·065450	·113097	·179594	·268082	·381703	0
1	·523599	·696910	·904779	1·150	1·437	1·767	2·145	2·572	3·054	3·591	1
2	4·189	4·849	5·575	6·371	7·238	8·181	9·203	10·306	11·494	12·770	2
3	14·137	15·598	17·157	18·816	20·579	22·449	24·429	26·522	28·731	31·059	3
4	33·510	36·087	38·792	41·630	44·602	47·713	50·965	54·362	57·906	61·601	4
5	65·450	69·456	73·622	77·952	82·448	87·114	91·952	96·967	102·160	107·536	5
6	113·097	118·847	124·788	130·924	137·258	143·793	150·533	157·479	164·636	172·007	6
7	179·594	187·402	195·432	203·689	212·175	220·893	229·847	239·040	248·475	258·155	7
8	268·083	278·262	288·696	299·387	310·339	321·555	333·038	344·791	356·818	369·121	8
9	381·703	394·569	407·720	421·160	434·893	448·921	463·247	477·875	492·807	508·047	9
Diam.	·0	0·1	0·2	0·3	0·4	0·5	0·6	0·7	0·8	0·9	Diam.

For each decimal point added to or subtracted from the diameter alter *three* decimal points in the tabular number.

Thus the contents of a sphere whose diameter is 5·8 = 102·160
" " " 58 = 102160
" " " ·58 = ·102

Logarithm of Numbers from 0 to 1000.

No.	0	1	2	3	4	5	6	7	8	9	Prop.
0	0	00000	30103	47712	60206	69897	77815	84510	90309	95424	
10	00000	00432	00860	01284	01703	02119	02531	02938	03342	03743	415
11	04139	04532	04922	05308	05690	06070	06446	06819	07188	07555	379
12	07918	08279	08636	08991	09342	09691	10037	10380	10721	11059	344
13	11394	11727	12057	12385	12710	13033	13354	13672	13988	14301	323
14	14613	14922	15229	15534	15836	16137	16435	16732	17026	17319	298
15	17609	17898	18184	18469	18752	19033	19312	19590	19866	20140	281
16	20412	20683	20952	21219	21484	21748	22011	22272	22531	22789	264
17	23045	23300	23553	23805	24055	24304	24551	24797	25042	25285	249
18	25527	25768	26007	26245	26482	26717	26951	27184	27416	27646	234
19	27875	28103	28330	28556	28780	29003	29226	29447	29667	29885	222
20	30103	30320	30535	30750	30963	31175	31387	31597	31806	32015	212
21	32222	32428	32634	32838	33041	33244	33445	33646	33846	34044	202
22	34242	34439	34635	34830	35025	35218	35411	35603	35793	35984	193
23	36173	36361	36549	36736	36922	37107	37291	37475	37658	37840	185
24	38021	38202	38382	38561	38739	38917	39094	39270	39445	39620	177
25	39794	39967	40140	40312	40483	40654	40824	40993	41162	41330	170
26	41497	41664	41830	41996	42160	42325	42488	42651	42813	42975	164
27	43136	43297	43457	43616	43775	43933	44091	44248	44404	44560	158
28	44716	44871	45025	45179	45332	45484	45637	45788	45939	46090	153
29	46240	46389	46538	46687	46835	46982	47129	47276	47422	47567	148
30	47712	47857	48001	48144	48287	48430	48572	48714	48855	48996	143
31	49136	49276	49415	49554	49693	49831	49969	50106	50243	50379	138
32	50515	50651	50786	50920	51055	51189	51322	51455	51587	51720	134
33	51851	51983	52114	52244	52375	52504	52634	52763	52892	53020	130
34	53148	53275	53403	53529	53656	53782	53908	54033	54158	54283	126
35	54407	54531	54654	54777	54900	55023	55145	55267	55388	55509	122
36	55630	55751	55871	55991	56110	56229	56348	56467	56585	56703	119
37	56820	56937	57054	57171	57287	57403	57519	57634	57749	57864	116
38	57978	58093	58206	58320	58433	58546	58659	58771	58883	58995	113
39	59106	59218	59329	59439	59550	59660	59770	59879	59988	60097	110
40	60206	60314	60423	60531	60638	60746	60853	60959	61066	61172	107

Indices of Logarithms:—

Log. 4030 = 3·60530
„ 403 = 2·60530
„ 40·3 = 1·60530

Log. 4·03 = ·60530
„ ·403 = $\bar{1}$·60530
„ ·0403 = $\bar{2}$·60530
„ ·00403 = $\bar{3}$·60530

LOGARITHM OF NUMBERS FROM 0 TO 1000—*continued.*

No.	0	1	2	3	4	5	6	7	8	9	Prop.
41	61278	61384	61490	61595	61700	61805	61909	62014	62118	62221	104
42	62325	62428	62531	62634	62737	62839	62941	63043	63144	63246	102
43	63347	63448	63548	63649	63749	63849	63949	64048	64147	64246	99
44	64345	64444	64542	64640	64738	64836	64933	65031	65128	65225	98
45	65321	65418	65514	65610	65706	65801	65896	65992	66087	66181	96
46	66276	66370	66464	66558	66652	66745	66839	66932	67025	67117	95
47	67210	67302	67394	67486	67578	67669	67761	67852	67943	68034	92
48	68124	68215	68305	68395	68485	68574	68664	68753	68842	68931	90
49	69020	69108	69197	69285	69373	69461	69548	69636	69723	69810	88
50	69897	69984	70070	70157	70243	70329	70415	70501	70586	70672	86
51	70757	70842	70927	71012	71096	71181	71265	71349	71433	71517	84
52	71600	71684	71767	71850	71933	72016	72099	72181	72263	72346	82
53	72428	72509	72591	72673	72754	72835	72916	72997	73078	73159	81
54	73239	73320	73400	73480	73560	73640	73719	73799	73878	73957	80
55	74036	74115	74194	74273	74351	74429	74507	74586	74663	74741	78
56	74819	74896	74974	75051	75128	75205	75282	75358	75435	75511	77
57	75587	75664	75740	75815	75891	75967	76042	76118	76193	76268	75
58	76343	76418	76492	76567	76641	76716	76790	76864	76938	77012	74
59	77085	77159	77232	77305	77379	77452	77525	77597	77670	77743	73
60	77815	77887	77960	78032	78104	78176	78247	78319	78390	78462	72
61	78533	78604	78675	78746	78817	78888	78958	79029	79099	79169	71
62	79239	79309	79379	79449	79518	79588	79657	79727	79796	79865	70
63	79934	80003	80072	80140	80209	80277	80346	80414	80482	80550	69
64	80618	80686	80754	80821	80889	80956	81023	81090	81158	81224	68
65	81291	81358	81425	81491	81558	81624	81690	81757	81823	81889	67
66	81954	82020	82086	82151	82217	82282	82347	82413	82478	82543	66
67	82607	82672	82737	82802	82866	82930	82995	83059	83123	83187	64
68	83251	83315	83378	83442	83506	83569	83632	83696	83759	83822	63
69	83885	83948	84011	84073	84136	84198	84261	84323	84386	84448	63
70	84510	84572	84634	84696	84757	84819	84880	84942	85003	85065	62

Find Log. of 5065
Log. of 5060 .. = 3·70415
Prop. 86 × Diff. 5 .. = 430

Log. required = 3·704580

Find number of Log. .. 3·771442
Log. of .. .. 5900 = 3·770850

Diff. 592 ÷ Prop. 73 = 8. Diff. = 592

No. required 5908

LOGARITHM OF NUMBERS FROM 0 TO 1000—*continued.*

No.	0	1	2	3	4	5	6	7	8	9	Prop.
71	85126	85187	85248	85309	85370	85431	85491	85552	85612	85673	61
72	85733	85794	85854	85914	85974	86034	86094	86153	86213	86273	60
73	86332	86392	86451	86510	86570	86629	86688	86747	86806	86864	59
74	86923	86982	87040	87099	87157	87216	87274	87332	87390	87448	58
75	87506	87564	87622	87680	87737	87795	87852	87910	87967	88024	57
76	88081	88138	88196	88252	88309	88366	88423	88480	88536	88593	57
77	88649	88705	88762	88818	88874	88930	88986	89042	89098	89154	56
78	89209	89265	89321	89376	89432	89487	89542	89597	89653	89708	55
79	89763	89818	89873	89927	89982	90037	90091	90146	90200	90255	54
80	90309	90363	90417	90472	90526	90580	90634	90687	90741	90795	54
81	90849	90902	90956	91009	91062	91116	91169	91222	91275	91328	53
82	91381	91434	91487	91540	91593	91645	91698	91751	91803	91855	53
83	91908	91960	92012	92065	92117	92169	92221	92273	92324	92376	52
84	92428	92480	92531	92583	92634	92686	92737	92788	92840	92891	51
85	92942	92993	93044	93095	93146	93197	93247	93298	93349	93399	51
86	93450	93500	93551	93601	93651	93702	93752	93802	93852	93902	50
87	93952	94002	94052	94101	94151	94201	94250	94300	94349	94399	49
88	94448	94498	94547	94596	94645	94694	94743	94792	94841	94890	49
89	94939	94988	95036	95085	95134	95182	95231	95279	95328	95376	48
90	95424	95472	95521	95569	95617	95665	95713	95761	95809	95856	48
91	95904	95952	95999	96047	96095	96142	96190	96237	96284	96332	48
92	96379	96426	96473	96520	96567	96614	96661	96708	96755	96802	47
93	96848	96895	96942	96988	97035	97081	97128	97174	97220	97267	47
94	97313	97359	97405	97451	97497	97543	97589	97635	97681	97727	46
95	97772	97818	97864	97909	97955	98000	98046	98091	98137	98182	46
96	98227	98272	98318	98363	98408	98453	98498	98543	98588	98632	45
97	98677	98722	98767	98811	98856	98900	98945	98989	99034	99078	45
98	99123	99167	99211	99255	99300	99344	99388	99432	99476	99520	44
99	99564	99607	99651	99695	99739	99782	99826	99870	99913	99957	44

To multiply by logarithms add the logarithms together and find the corresponding number.

To divide by logarithms subtract one from the other.

To extract the root divide the logarithm by the index of the root and find the number corresponding to it.

To raise a number to any power multiply the logarithm by the index of the power and find the corresponding number.

Involution and Evolution of Fractions by Logarithms.

In a logarithm the integer is called the *characteristic*, and the decimal portion the *mantissa*.

Involution.—The number carried from the *mantissa* to the *characteristic* being positive, must be deducted from the negative characteristic.

Example.—Find the 5th power of ·05, or the value of $\cdot 05^5$.

$$\text{Log. } \cdot 05 = \bar{2}\cdot 69897$$
$$\text{then } \bar{2} \times 5 = \overline{10}$$
$$+$$
$$\text{and } \cdot 69897 \times 5 = 3\cdot 49485$$

$$\text{Then log. } \cdot 05^5 = \bar{7}\cdot 49485$$
$$\text{and } \cdot 05^5 = \cdot 0000003125.$$

Evolution.—If the *negative* characteristic be not divisible without a remainder by the index of the required root, the number of units sufficient to make it so divisible must be added to it, and the same number of units must also be added to the mantissa before division.

Example.—Find the value of $\sqrt[5]{\cdot 0000003125}$.

$$\text{Log. } \cdot 0000003125 = \bar{7}\cdot 49485$$
$$\text{then } \bar{7} + \bar{3} = \overline{10}, \text{ and } \overline{10} \div 5 = \bar{2}$$
$$\text{and } 3\cdot 49485 \div 5 = \cdot 69897$$

$$\text{Therefore log. } \sqrt[5]{\cdot 0000003125} = \bar{2}\cdot 69897 = \text{log. of } \cdot 05.$$

Proportion by Logarithms.

Add together the logarithms of the 2nd and 3rd terms, and from their sum subtract the logarithm of the 1st term, then the number corresponding to the logarithm of the remainder gives the required answer.

Example.—68·30 : 13·70 : : 79·40.

$$\text{Log. } 13\cdot 70 = 1\cdot 13672$$
$$\text{Log. } 79\cdot 40 = 1\cdot 89982$$

$$\text{Sum } 3\cdot 03654$$
$$\text{Log. } 68\cdot 30 = 1\cdot 83442$$

$$\text{Diff. } 1\cdot 20212 = \text{log. of } 15\cdot 93.$$

Slide Rule.

The common slide rule consists of 4 scales; A and D fixed, and B and C sliding. All are spaced as the logarithms of the numbers they represent, so that by sliding one scale against another, logarithmic functions are mechanically performed.

A, B, and C are identical in their divisions, whilst the divisions of D are twice the size of those on the other scales, or spaced as the logarithms of the square roots of the other scales.

Examples of Working the Slide Rule.

In the following examples the letters A, B, C, D denote the respective scales on which the reading is to be found; P denotes the gauge point (see below); d = diameter, or side of square; l = length; w = weight, or cubic contents; C_1 and C_2 denote the first and second half of C scale respectively. In questions involving the square root: if the number of digits be *odd*, the working must be on A_1 or C_1; but if the number of digits be *even*, it must be on A_2 or C_2, as the case may be. In questions not involving any root or power it is immaterial whether the working is on the first or second half of the scale.

		Case.	1st Term.	2nd Term.	3rd Term.	4th Term.
			Set	on	and against	is Answer.
1	Multiplication	12×23	1 B	23 A	12 B	276 A
2	Division	$54 \div 24$	24 A	1 B	54 A	2·25 B
3	Proportion	7 : 54 : : 31	7 B	54 A	31 B	239 A
4	Inverse Proportion (Invert Slide)	7 : 54 : : x : 239	7 C	239 A	54 C	31 A
5	CircleCircumference (P = 3·14) ..	for $d = 15$	1 B	3·14 A	15 B	47·1 A
6	Circle Area (P = ·785)	for $d = 6·35$	1 A	·785 B	6·35 D	31·7 C
7	Strength, Weight, or Contents ..	$d^2 \div P$	P A	1·B	d D	w C
8	Mensuration of Solids	$l\,d^2 \div P$	P A	l B	d D	w C
9	Contents of Sphere or Cube	$d^3 \div P$	P A	d B	d D	w C
10	Squaring	$(5·5)^2$	1 D	1 C	5·5 D	30·25 C_2
11	Square Root (digits odd)	$\sqrt{6·5}$	1 C	1 D	6·5 C_1	2·55 D
12	Ditto (digits even) ..	$\sqrt{65}$	1 C	1 D	65 C_2	8·06 D
13	Side of Square or Rectangle ..	$\sqrt{25 \times 76}$	76 C	76 D	25 C	43·6 D
14	Cube	$(7·3)^3$	10 D	7·3 C	7·3 D	389 C

Slide Rule—*continued.*

The "gauge-point" P = the number of units of the dimension contained in the unit of the answer. Thus if answer and dimensions are all in feet, P = 1; for answer in feet with dimensions F.I.I (feet × inches × inches), $P = 1 \times 12 \times 12 = 144$; for answer in inches with dimensions F.F.I, $P = 1 \times \frac{1}{12} \times \frac{1}{12} = \cdot 00694$; &c.

On some slide rules 1 A is opposite 4 D, in which case the gauge points for the ordinary slide rule must be divided by 16 (4^2).

The slide rule is a proportional instrument, and a given case should be reduced to the proportional form $a : b :: c : x$. Terms a and b or c and x must never fall on the same line.

If A and B be set to any proportion, then all the numbers against each other in the same lines will be in the same ratio; thus if the gauge point for the circumference of a circle on B be set on 1 A, all the numbers on B will represent a table of circumferences due to the diameter represented by the figures on A.

With the gauge point, P, for areas on B, set against 1 A, the scale C forms a table of areas of circles for diameters represented by the figures on D. With 1 C set on 1 D, the scales C and D are tables of squares and square roots respectively for the numbers of the scales opposite to them.

Cases of $x = \sqrt[n]{a^m}$ or $a^{\frac{m}{n}}$ may be readily solved by the aid of an equal parts scale applied to a slide-rule line. Thus for $\sqrt[5]{\cdot 16^3}$, if the distance from ·16 to 1 of a slide rule measure 378 on a scale of 80, then $378 \times \frac{3}{5} = 22 \cdot 7$, and from 0 to 22·7 on the 80 scale reaches back from 1 to $\cdot 333 = x$ on the slide-rule scale.

Gauge Points on Routlege's Slide Rule.

	Cube Ins.	Cube Feet.	Gallons.	Water.	Wt. Iron.	Cast Iron.	Brass	Copper.	Lead.	Tin.
F F F	578	1	163	16	207	222	193	18	141	219
F I I	88	144	231	23	297	32	218	26	203	315
I I I	1	1728	277	2765	357	384	333	312	243	378
F I	106	1833	249	293	378	407	354	331	258	401
I I	1273	22	353	352	453	489	424	397	31	481
F	106	191	306	305	394	414	369	345	27	429
I	191	33	529	528	682	733	637	596	465	723

Deg.	Sine.	Cosecant.	Versin.	Tangent.	Cotangent.	Coversin.	Secant.	Cosine.	Deg.
0	Inf. Neg.	Infinite.	Inf. Neg.	Inf. Neg.	Infinite.	10·00000	10·00000	10·00000	90
1	8·24186	11·75814	6·18271	8·24192	11·75808	9·99235	10·00007	9·99993	89
2	8·54282	11·45718	6·78474	8·54308	11·45692	9·98457	10·00026	9·99974	88
3	8·71880	11·28120	7·13687	8·71940	11·28060	9·97665	10·00060	9·99940	87
4	8·84358	11·15642	7·38667	8·84464	11·15536	9·96860	10·00106	9·99894	86
5	8·94030	11·05970	7·58039	8·94195	11·05805	9·96040	10·00166	9·99834	85
6	9·01923	10·98077	7·73863	9·02162	10·97838	9·95205	10·00239	9·99761	84
7	9·08589	10·91411	7·87238	9·08914	10·91086	9·94356	10·00325	9·99675	83
8	9·14356	10·85644	7·98820	9·14780	10·85220	9·93492	10·00425	9·99575	82
9	9·19433	10·80567	8·09032	9·19971	10·80029	9·92612	10·00538	9·99462	81
10	9·23967	10·76033	8·18162	9·24632	10·75368	9·91717	10·00665	9·99335	80
11	9·28060	10·71940	8·26418	9·28865	10·71135	9·90805	10·00805	9·99195	79
12	9·31788	10·68212	8·33950	9·32747	10·67253	9·89877	10·00960	9·99040	78
13	9·35209	10·64791	8·40875	9·36336	10·63664	9·88933	10·01128	9·98872	77
14	9·38368	10·61632	8·47282	9·39677	10·60323	9·87971	10·01310	9·98690	76
15	9·41300	10·58700	8·53243	9·42805	10 57195	9·86992	10·01506	9·98494	75
	Cosine.	Secant.	Coversin.	Cotangent.	Tangent	Versin.	Cosecant.	Sine.	

LOGARITHMIC SINES, &c.—*continued.*

Deg.	Sine.	Cosecant.	Versin.	Tangent.	Cotangent.	Coversin.	Secant.	Cosine.	Deg.
16	9·44034	10·55966	8·58814	9·45750	10·54250	9·85996	10·01716	9·98284	74
17	9·46594	10·53406	8·64043	9·48534	10·51466	9·84981	10·01940	9·98060	73
18	9·48998	10·51002	8·68969	9·51178	10·48822	9·83947	10·02179	9·97821	72
19	9·51264	10·48736	8·73625	9·53697	10·46303	9·82894	10·02433	9·97567	71
20	9·53405	10·46595	8·78037	9·56107	10·43893	9·81821	10·02701	9·97299	70
21	9·55433	10·44567	8·82230	9·58418	10·41582	9·80729	10·02985	9·97015	69
22	9·57358	10·42642	8·86223	9·60641	10·39359	9·79615	10·03283	9·96717	68
23	9·59188	10·40812	8·90034	9·62785	10·37215	9·78481	10·03597	9·96403	67
24	9·60931	10·39069	8·93679	9·64858	10·35142	9·77325	10·03927	9·96073	66
25	9·62595	10·37405	8·97170	9·66867	10·33133	9·76146	10·04272	9·95728	65
26	9·64184	10·35816	9·00521	9·68818	10·31182	9·74945	10·04634	9·95366	64
27	9·65705	10·34295	9·03740	9·70717	10·29283	9·73720	10·05012	9·94988	63
28	9·67161	10·32839	9·06838	9·72567	10·27433	9·72471	10·05407	9·94593	62
29	9·68557	10·31443	9·09823	9·74375	10·25625	9·71197	10·05818	9·94182	61
30	9·69897	10·30103	9·12702	9·76144	10·23856	9·69897	10·06247	9·93753	60
	Cosine.	Secant.	Coversin.	Cotangent.	Tangent.	Versin.	Cosecant.	Sine.	

LOGARITHMIC.

LOGARITHMIC SINES, &c.—*continued.*

Deg.	Sine.	Cosecant.	Versin.	Tangent.	Cotangent.	Coversin.	Secant.	Cosine.	Deg.
31	9·71184	10·28816	9·15483	9·77877	10·22123	9·68571	10·06693	9·93307	59
32	9·72421	10·27579	9·18171	9·79579	10·20421	9·67217	10·07158	9·92842	58
33	9·73611	10·26389	9·20771	9·81252	10·18748	9·65836	10·07641	9·92359	57
34	9·74756	10·25244	9·23290	9·82899	10·17101	9·64425	10·08143	9·91857	56
35	9·75859	10·24141	9·25731	9·84523	10·15477	9·62984	10·08664	9·91336	55
36	9·76922	10·23078	9·28099	9·86126	10·13874	9·61512	10·09204	9·90796	54
37	9·77946	10·22054	9·30398	9·87711	10·12289	9·60008	10·09765	9·90235	53
38	9·78934	10·21066	9·32631	9·89281	10·10719	9·58471	10·10347	9·89653	52
39	9·79887	10·20113	9·34802	9·90837	10·09163	9·56900	10·10950	9·89050	51
40	9·80807	10·19193	9·36913	9·92381	10·07619	9·55293	10·11575	9·88425	50
41	9·81694	10·18306	9·38968	9·93916	10·06084	9·53648	10·12222	9·87778	49
42	9·82551	10·17449	9·40969	9·95444	10·04556	9·51966	10·12893	9·87107	48
43	9·83378	10·16622	9·42918	9·96966	10·03034	9·50243	10·13587	9·86413	47
44	9·84177	10·15823	9·44818	9·98484	10·01516	9·48479	10·14307	9·85693	46
45	9·84949	10·15052	9·46671	10·00000	10·00000	9·46671	10·15052	9·84949	45
	Cosine.	Secant.	Coversin.	Cotangent.	Tangent.	Versin.	Cosecant.	Sine.	

LOGARITHMIC.

Hyperbolic Logarithms.

Calculated by LEWIS OLRICK, C.E.

The hyperbolic logarithm of a number is found by multiplying the common logarithm of the number by 2·302585052994.

Example:— The common logarithm of 7 is 0·8450980, which multiplied by 2·30258505 gives 1·9459100, the hyperbolic logarithm.

No.	Logarithm.	No.	Logarithm.	No.	Logarithm.	No.	Logarithm.
1·01	·0099503	1·26	·2311116	1·51	·4121095	1·76	·5653138
1·02	·0198026	1·27	·2390169	1·52	·4187103	1·77	·5709795
1·03	·0295588	1·28	·2468601	1·53	·4252676	1·78	·5766133
1·04	·0392207	1·29	·2546422	1·54	·4317825	1·79	·5822156
1·05	·0487902	1·30	·2623643	1·55	·4382549	1·80	·5877866
1·06	·0582690	1·31	·2700271	1·56	·4446858	1·81	·5933268
1·07	·0676586	1·32	·2776317	1·57	·4510756	1·82	·5988365
1·08	·0769610	1·33	·2851788	1·58	·4574249	1·83	·6043159
1·09	·0861777	1·34	·2926696	1·59	·4637339	1·84	·6097655
1·10	·0953102	1·35	·3001046	1·60	·4700036	1·85	·6151856
1·11	·1043600	1·36	·3074847	1·61	·4762341	1·86	·6205764
1·12	·1133286	1·37	·3148108	1·62	·4824261	1·87	·6259384
1·13	·1222175	1·38	·3220835	1·63	·4885801	1·88	·6312717
1·14	·1310284	1·39	·3293037	1·64	·4946961	1·89	·6365768
1·15	·1397618	1·40	·3364722	1·65	·5007752	1·90	·6418538
1·16	·1484200	1·41	·3435897	1·66	·5068176	1·91	·6471033
1·17	·1570038	1·42	·3506568	1·67	·5128237	1·92	·6523251
1·18	·1655144	1·43	·3576744	1·68	·5187938	1·93	·6575200
1·19	·1739534	1·44	·3646431	1·69	·5247285	1·94	·6626879
1·20	·1823215	1·45	·3715635	1·70	·5306282	1·95	·6678294
1·21	·1906204	1·46	·3784365	1·71	·5364933	1·96	·6729445
1·22	·1988508	1·47	·3852623	1·72	·5423242	1·97	·6780335
1·23	·2070141	1·48	·3920420	1·73	·5481214	1·98	·6830968
1·24	·2151113	1·49	·3987762	1·74	·5538850	1·99	·6881346
1·25	·2231435	1·50	·4054652	1·75	·5596157	2·00	·6931472

Hyperbolic Logarithms—*continued.*

No.	Logarithm.	No.	Logarithm.	No	Logarithm.	No.	Logarithm.
2·01	·6981347	2·36	·8586616	2·71	·9969486	3·06	1·118414[illegible]
2·02	·7030974	2·37	·8628899	2·72	1·0006318	3·07	1·121677[illegible]
2·03	·7080357	2·38	·8671004	2·73	1·0043015	3·08	1·1249295
2·04	·7129497	2·39	·8712933	2·74	1·0079579	3·09	1·1281710
2·05	·7178399	2·40	·8754686	2·75	1·0116009	3·10	1·1314021
2·06	·7227059	2·41	·8796266	2·76	1·0152306	3·11	1·1346227
2·07	·7275485	2·42	·8837675	2·77	1·0188473	3·12	1·1378330
2·08	·7323678	2·43	·8878912	2·78	1·0224509	3·13	1·1410330
2·09	·7371640	2·44	·8919980	2·79	1·0260415	3·14	1·1442227
2·10	·7419373	2·45	·8960881	2·80	1·0296193	3·15	1·1474024
2·11	·7466880	2·46	·9001613	2·81	1·0331844	3·16	1·1505720
2·12	·7514160	2·47	·9042181	2·82	1·0367368	3·17	1·1537315
2·13	·7561219	2·48	·9082585	2·83	1·0402766	3·18	1·1568811
2·14	·7608058	2·49	·9122826	2·84	1·0438040	3·19	1·1600209
2·15	·7654679	2·50	·9162907	2·85	1·0473189	3·20	1·1631508
2·16	·7701082	2·51	·9202827	2·86	1·0508215	3·21	1·1662708
2·17	·7747271	2·52	·9242589	2·87	1·0543120	3·22	1·1693813
2·18	·7793248	2·53	·9282193	2·88	1·0577902	3·23	1·1724821
2·19	·7839015	2·54	·9321640	2·89	1·0612564	3·24	1·1755733
2·20	·7884573	2·55	·9360934	2·90	1·0647107	3·25	1·1786549
2·21	·7929925	2·56	·9400072	2·91	1·0681531	3·26	1·1817271
2·22	·7975071	2·57	·9439058	2·92	1·0715836	3·27	1·1847899
2·23	·8020015	2·58	·9477893	2·93	1·0750024	3·28	1·1878434
2·24	·8064758	2·59	·9516578	2·94	1·0784095	3·29	1·1908875
2·25	·8109303	2·60	·9555113	2·95	1·0818051	3·30	1·1939224
2·26	·8153647	2·61	·9593502	2·96	1·0851892	3·31	1·1969481
2·27	·8197798	2·62	·9631743	2·97	1·0885619	3·32	1·1999647
2·28	·8241754	2·63	·9669838	2·98	1·0919233	3·33	1·2029722
2·29	·8285518	2·64	·9707789	2·99	1·0952733	3·34	1·2059707
2·30	·8329090	2·65	·9745596	3·00	1·0986124	3·35	1·2089603
2·31	·8372476	2·66	·9783260	3·01	1·1019400	3·36	1·2119409
2·32	·8415671	2·67	·9820784	3·02	1·1052568	3·37	1·2149127
2·33	·8458682	2·68	·9858167	3·03	1·1085626	3·38	1·2178757
2·34	·8501509	2·69	·9895411	3·04	1·1118575	3·39	1·2208299
2·35	·8544154	2·70	·9932518	3·05	1·1151415	3·40	1·2237754

Hyperbolic Logarithms—*continued.*

No.	Logarithm.	No.	Logarithm.	No.	Logarithm.	No.	Logarithm.
3·41	1·2267122	3·76	1·3244189	4·11	1·4134230	4·46	1·4951487
3·42	1·2296405	3·77	1·3270749	4·12	1·4158531	4·47	1·4973883
3·43	1·2325605	3·78	1·3297240	4·13	1·4182774	4·48	1·4996230
3·44	1·2354714	3·79	1·3323660	4·14	1·4206957	4·49	1·5018527
3·45	1·2383742	3·80	1·3350010	4·15	1·4231083	4·50	1·5040773
3·46	1·2412685	3·81	1·3376291	4·16	1·4255150	4·51	1·5062971
3·47	1·2441545	3·82	1·3402504	4·17	1·4279161	4·52	1·5085119
3·48	1·2470322	3·83	1·3428648	4·18	1·4303112	4·53	1·5107219
3·49	1·2499017	3·84	1·3454723	4·19	1·4327007	4·54	1·5129269
3·50	1·2527629	3·85	1·3480731	4·20	1·4350845	4·55	1·5151272
3·51	1·2556160	3·86	1·3506671	4·21	1·4374626	4·56	1·5173226
3·52	1·2584609	3·87	1·3532544	4·22	1·4398351	4·57	1·5195132
3·53	1·2612978	3·88	1·3558351	4·23	1·4422020	4·58	1·5216990
3·54	1·2641266	3·89	1·3584091	4·24	1·4445632	4·59	1·5238800
3·55	1·2669475	3·90	1·3609765	4·25	1·4469189	4·60	1·5260563
3·56	1·2697605	3·91	1·3635373	4·26	1·4492691	4·61	1·5282278
3·57	1·2725655	3·92	1·3660916	4·27	1·4516138	4·62	1·5303947
3·58	1·2753627	3·93	1·3686395	4·28	1·4539530	4·63	1·5325568
3·59	1·2781521	3·94	1·3711807	4·29	1·4562867	4·64	1·5347143
3·60	1·2809338	3·95	1·3737156	4·30	1·4586149	4·65	1·5368672
3·61	1·2837077	3·96	1·3762440	4·31	1·4609379	4·66	1·5390154
3·62	1·2864740	3·97	1·3787661	4·32	1·4632553	4·67	1·5411590
3·63	1·2892326	3·98	1·3812818	4·33	1·4655675	4·68	1·5432981
3·64	1·2919836	3·99	1·3837912	4·34	1·4678743	4·69	1·5454325
3·65	1·2947271	4·00	1·3862943	4·35	1·4701758	4·70	1·5475625
3·66	1·2974631	4·01	1·3887912	4·36	1·4724720	4·71	1·5496879
3·67	1·3001916	4·02	1·3912818	4·37	1·4747630	4·72	1·5518087
3·68	1·3029127	4·03	1·3937763	4·38	1·4770487	4·73	1·5539252
3·69	1·3056264	4·04	1·3962446	4·39	1·4793292	4·74	1·5560371
3·70	1·3083328	4·05	1·3987168	4·40	1·4816045	4·75	1·5581446
3·71	1·3110318	4·06	1·4011829	4·41	1·4838746	4·76	1·5602476
3·72	1·3137236	4·07	1·4036429	4·42	1·4861396	4·77	1·5623462
3·73	1·3164082	4·08	1·4060969	4·43	1·4883995	4·78	1·5644405
3·74	1·3190856	4·09	1·4085449	4·44	1·4906543	4·79	1·5665304
3·75	1·3217559	4·10	1·4109869	4·45	1·4929040	4·80	1·5686159

HYPERBOLIC LOGARITHMS—*continued.*

No.	Logarithm.	No.	Logarithm.	No.	Logarithm.	No.	Logarithm.
4·81	1·5706971	5·16	1·6409365	5·51	1·7065646	5·86	1·7681496
4·82	1·5727739	5·17	1·6428726	5·52	1·7083778	5·87	1·7698546
4·83	1·5748464	5·18	1·6448050	5·53	1·7101878	5·88	1·7715567
4·84	1·5769147	5·19	1·6467336	5·54	1·7119944	5·89	1·7732559
4·85	1·5789787	5·20	1·6486586	5·55	1·7137979	5·90	1·7749523
4·86	1·5810384	5·21	1·6505798	5·56	1·7155981	5·91	1·7768458
4·87	1·5830939	5·22	1·6524974	5·57	1·7173950	5·92	1·7783364
4·88	1·5851452	5·23	1·6544112	5·58	1·7191887	5·93	1·7800242
4·89	1·5871923	5·24	1·6563214	5·59	1·7209792	5·94	1·7817091
4·90	1·5892352	5·25	1·6582280	5·60	1·7227655	5·95	1·7833912
4·91	1·5912739	5·26	1·6601310	5·61	1·7245507	5·96	1·7850704
4·92	1·5933085	5·27	1·6620303	5·62	1·7263316	5·97	1·7867469
4·93	1·5953389	5·28	1·6639260	5·63	1·7281094	5·98	1·7884205
4·94	1·5973653	5·29	1·6658182	5·64	1·7298840	5·99	1·7900914
4·95	1·5993875	5·30	1·6677068	5·65	1·7316555	6·00	1·7917595
4·96	1·6014057	5·31	1·6695918	5·66	1·7334238	6·01	1·7934247
4·97	1·6034193	5·32	1·6714733	5·67	1·7351891	6·02	1·7950872
4·98	1·6054298	5·33	1·6733512	5·68	1·7369512	6·03	1·7967470
4·99	1·6074358	5·34	1·6752256	5·69	1·7387102	6·04	1·7984040
5·00	1·6094379	5·35	1·6770965	5·70	1·7404661	6·05	1·8000582
5·01	1·6114359	5·36	1·6789639	5·71	1·7422189	6·06	1·8017098
5·02	1·6134300	5·37	1·6808278	5·72	1·7439687	6·07	1·8033586
5·03	1·6154200	5·38	1·6826882	5·73	1·7457155	6·08	1·8050047
5·04	1·6174060	5·39	1·6845453	5·74	1·7474591	6·09	1·8066481
5·05	1·6193882	5·40	1·6863989	5·75	1·7491998	6·10	1·8082887
5·06	1·6213664	5·41	1·6882491	5·76	1·7509374	6·11	1·8099267
5·07	1·6233408	5·42	1·6900958	5·77	1·7526720	6·12	1·8115621
5·08	1·6253112	5·43	1·6919391	5·78	1·7544036	6·13	1·8131947
5·09	1·6272778	5·44	1·6937790	5·79	1·7561323	6·14	1·8148247
5·10	1·6292405	5·45	1·6956155	5·80	1·7578579	6·15	1·8164520
5·11	1·6311994	5·46	1·6974487	5·81	1·7595805	6·16	1·8180767
5·12	1·6331544	5·47	1·6992786	5·82	1·7613002	6·17	1·8196988
5·13	1·6351057	5·48	1·7011051	5·83	1·7630170	6·18	1·8213182
5·14	1·6370530	5·49	1·7029282	5·84	1·7647308	6·19	1·8229351
5·15	1·6389967	5·50	1·7047481	5·85	1·7664416	6·20	1·8245493

HYPERBOLIC LOGARITHMS—*continued.*

No.	Logarithm.	No.	Logarithm.	No.	Logarithm.	No.	Logarithm.
6·21	1·8261608	6·56	1·8809906	6·91	1·9329696	7·26	1·9823798
6·22	1·8277699	6·57	1·8825138	6·92	1·9344157	7·27	1·9837562
6·23	1·8293763	6·58	1·8840347	6·93	1·9358598	7·28	1·9851308
6·24	1·8309801	6·59	1·8855533	6·94	1·9373017	7·29	1·9865035
6·25	1·8325814	6·60	1·8870697	6·95	1·9387416	7·30	1·9878743
6·26	1·8341801	6·61	1·8885837	6·96	1·9401794	7·31	1·9892432
6·27	1·8357763	6·62	1·8900954	6·97	1·9416152	7·32	1·9906103
6·28	1·8373699	6·63	1·8916048	6·98	1·9430489	7·33	1·9919754
6·29	1·8389610	6·64	1·8931119	6·99	1·9444805	7·34	1·9933387
6·30	1·8405496	6·65	1·8946168	7·00	1·9459100	7·35	1·9947002
6·31	1·8421356	6·66	1·8961194	7·01	1·9473376	7·36	1·9960599
6·32	1·8437191	6·67	1·8976198	7·02	1·9487632	7·37	1·9974177
6·33	1·8453002	6·68	1·8991179	7·03	1·9501866	7·38	1·9987736
6·34	1·8468787	6·69	1·9006138	7·04	1·9516080	7·39	2·0001278
6·35	1·8484547	6·70	1·9021075	7·05	1·9530275	7·40	2·0014800
6·36	1·8500283	6·71	1·9035989	7·06	1·9544449	7·41	2·0028305
6·37	1·8515994	6·72	1·9050881	7·07	1·9558604	7·42	2·0041790
6·38	1·8531680	6·73	1·9065751	7·08	1·9572739	7·43	2·0055258
6·39	1·8547342	6·74	1·9080600	7·09	1·9586853	7·44	2·0068708
6·40	1·8562979	6·75	1·9095425	7·10	1·9600947	7·45	2·0082140
6·41	1·8578592	6·76	1·9110228	7·11	1·9615022	7·46	2·0095553
6·42	1·8594181	6·77	1·9125011	7·12	1·9629077	7·47	2·0108949
6·43	1·8609745	6·78	1·9139771	7·13	1·9643112	7·48	2·0122327
6·44	1·8625285	6·79	1·9154509	7·14	1·9657127	7·49	2·0135687
6·45	1·8640801	6·80	1·9169226	7·15	1·9671123	7·50	2·0149030
6·46	1·8656293	6·81	1·9183921	7·16	1·9685099	7·51	2·0162354
6·47	1·8671761	6·82	1·9198594	7·17	1·9699056	7·52	2·0175661
6·48	1·8687205	6·83	1·9213247	7·18	1·9712993	7·53	2·0188950
6·49	1·8702625	6·84	1·9227877	7·19	1·9726911	7·54	2·0202221
6·50	1·8718021	6·85	1·9242486	7·20	1·9740810	7·55	2·0215475
6·51	1·8733394	6·86	1·9257074	7·21	1·9754689	7·56	2·0228711
6·52	1·8748743	6·87	1·9271641	7·22	1·9768549	7·57	2·0241929
6·53	1·8764069	6·88	1·9286186	7·23	1·9782390	7·58	2·0255131
6·54	1·8779371	6·89	1·9300710	7·24	1·9796212	7·59	2·0268315
6·55	1·8794650	6·90	1·9315214	7·25	1·9810014	7·60	2·0281482

HYPERBOLIC LOGARITHMS—*continued.*

No.	Logarithm.	No.	Logarithm.	No.	Logarithm.	No.	Logarithm.
7·61	2·0294631	7·96	2·0744290	8·31	2·1174596	8·66	2·1587147
7·62	2·0307763	7·97	2·0756845	8·32	2·1186622	8·67	2·1598687
7·63	2·0320878	7·98	2·0769384	8·33	2·1198634	8·68	2·1610215
7·64	2·0333976	7·99	2·0781907	8·34	2·1210632	8·69	2·1621729
7·65	2·0347056	8·00	2·0794414	8·35	2·1222615	8·70	2·1633230
7·66	2·0360119	8·01	2·0806907	8·36	2·1234584	8·71	2·1644718
7·67	2·0373166	8·02	2·0819384	8·37	2·1246539	8·72	2·1656192
7·68	2·0386195	8·03	2·0831845	8·38	2·1258479	8·73	2·1667653
7·69	2·0399207	8·04	2·0844290	8·39	2·1270405	8·74	2·1679101
7·70	2·0412203	8·05	2·0856720	8·40	2·1282317	8·75	2·1690536
7·71	2·0425181	8·06	2·0869135	8·41	2·1294214	8·76	2·1701959
7·72	2·0438143	8·07	2·0881534	8·42	2·1306098	8·77	2·1713367
7·73	2·0451088	8·08	2·0893918	8·43	2·1317967	8·78	2·1724763
7·74	2·0464016	8·09	2·0906287	8·44	2·1329822	8·79	2·1736146
7·75	2·0476928	8·10	2·0918640	8·45	2·1341664	8·80	2·1747517
7·76	2·0489823	8·11	2·0930984	8·46	2·1353491	8·81	2·1758874
7·77	2·0502701	8·12	2·0943306	8·47	2·1365304	8·82	2·1770218
7·78	2·0515563	8·13	2·0955613	8·48	2·1377104	8·83	2·1781550
7·79	2·0528408	8·14	2·0967905	8·49	2·1388889	8·84	2·1792868
7·80	2·0541237	8·15	2·0980182	8·50	2·1400661	8·85	2·1804174
7·81	2·0554049	8·16	2·0992444	8·51	2·1412410	8·86	2·1815467
7·82	2·0566845	8·17	2·1004691	8·52	2·1424163	8·87	2·1826747
7·83	2·0579624	8·18	2·1016923	8·53	2·1435893	8·88	2·1838015
7·84	2·0592388	8·19	2·1029140	8·54	2·1447609	8·89	2·1849270
7·85	2·0605135	8·20	2·1041341	8·55	2·1459312	8·90	2·1860512
7·86	2·0617866	8·21	2·1053529	8·56	2·1471001	8·91	2·1871742
7·87	2·0630580	8·22	2·1065702	8·57	2·1482676	8·92	2·1882959
7·88	2·0643278	8·23	2·1077861	8·58	2·1494339	8·93	2·1894163
7·89	2·0655961	8·24	2·1089998	8·59	2·1505987	8·94	2·1905355
7·90	2·0668627	8·25	2·1102128	8·60	2·1517622	8·95	2·1916535
7·91	2·0681277	8·26	2·1114243	8·61	2·1529243	8·96	2·1927702
7·92	2·0693911	8·27	2·1126343	8·62	2·1540851	8·97	2·1938856
7·93	2·0706530	8·28	2·1138428	8·63	2·1552445	8·98	2·1949998
7·94	2·0719132	8·29	2·1150499	8·64	2·1564026	8·99	2·1961128
7·95	2·0731719	8·30	2·1162555	8·65	2·1575593	9·00	2·1972245

Hyperbolic Logarithms—*continued.*

No.	Logarithm.	No.	Logarithm.	No.	Logarithm.	No.	Logarithm.
9·01	2·1983351	9·26	2·2257040	9·51	2·2523439	9·76	2·2782924
9·02	2·1994443	9·27	2·2267834	9·52	2·2533947	9·77	2·2793165
9·03	2·2005524	9·28	2·2278615	9·53	2·2544446	9·78	2·2803395
9·04	2·2016592	9·29	2·2289385	9·54	2·2554935	9·79	2·2813615
9·05	2·2027648	9·30	2·2300144	9·55	2·2565411	9·80	2·2823824
9·06	2·2038691	9·31	2·2310891	9·56	2·2575877	9·81	2·2834023
9·07	2·2049723	9·32	2·2321626	9·57	2·2586332	9·82	2·2844211
9·08	2·2060742	9·33	2·2332350	9·58	2·2596775	9·83	2·2854389
9·09	2·2071749	9·34	2·2343062	9·59	2·2607209	9·84	2·2864557
9·10	2·2082774	9·35	2·2353763	9·60	2·2617631	9·85	2·2874715
9·11	2·2093727	9·36	2·2364453	9·61	2·2628042	9·86	2·2884862
9·12	2·2104698	9·37	2·2375131	9·62	2·2638443	9·87	2·2894999
9·13	2·2115657	9·38	2·2385797	9·63	2·2648832	9·88	2·2905125
9·14	2·2126604	9·39	2·2396453	9·64	2·2659211	9·89	2·2915241
9·15	2·2137539	9·40	2·2407097	9·65	2·2669579	9·90	2·2925348
9·16	2·2148462	9·41	2·2417729	9·66	2·2679936	9·91	2·2935444
9·17	2·2159373	9·42	2·2428351	9·67	2·2690283	9·92	2·2945529
9·18	2·2170272	9·43	2·2438961	9·68	2·2700619	9·93	2·2955605
9·19	2·2181159	9·44	2·2449560	9·69	2·2710944	9·94	2·2965670
9·20	2·2192035	9·45	2·2460147	9·70	2·2721259	9·95	2·2975726
9·21	2·2202898	9·46	2·2470724	9·71	2·2731563	9·96	2·2985771
9·22	2·2213750	9·47	2·2481289	9·72	2·2741856	9·97	2·2995806
9·23	2·2224590	9·48	2·2491843	9·73	2·2752139	9·98	2·3005831
9·24	2·2235419	9·49	2·2502386	9·74	2·2762411	9·99	2·3015846
9·25	2·2246236	9·50	2·2512918	9·75	2·2772673	10	2·3025851

Useful Logarithms.		Constant.	Logarithm.
Base of Naperian system	ϵ	2·718281828	0·4342945
Modulus of Briggs' system	M	·434294482	$\bar{1}$·6377843
Reciprocal of Modulus	k	2·302585093	·3622216
Velocity of falling body, ft. in 1 sec.	g	32·19084	1·5077222
Equatorial radius of earth feet	—	20,923,600	7·3206364
Polar " " "	—	20,853,657	7·3191823
Degree in latitude, Equator "	—	362,750	5·5596090
" " Pole "	—	366,396	5·5639504
" longitude, Equator "	—	365,186	5·5625138

Squares, Cubes, Square Roots, and Cube Roots.

No.	Square.	Cube.	Square Root.	Cube Root.	No.	Square.	Cube.	Square Root.	Cube Root.
1	1	1	1·0	1·0	41	1681	68921	6·40312	3·4482
2	4	8	1·41421	1·2599	42	1764	74088	6·48074	3·4760
3	9	27	1·73205	1·4422	43	1849	79507	6·55744	3·5034
4	16	64	2·0	1·5874	44	1936	85184	6·63325	3·5303
5	25	125	2·23607	1·7100	45	2025	91125	6·70820	3·5569
6	36	216	2·44949	1·8171	46	2116	97336	6·78233	3·5830
7	49	343	2·64575	1·9129	47	2209	103823	6·85565	3·6088
8	64	512	2·82843	2·0	48	2304	110592	6·92820	3·6342
9	81	729	3·0	2·0801	49	2401	117649	7·0	3·6593
10	100	1000	3·16228	2·1544	50	2500	125000	7·07107	3·6840
11	121	1331	3·31662	2·2240	51	2601	132651	7·14143	3·7084
12	144	1728	3·46410	2·2894	52	2704	140608	7·21110	3·7325
13	169	2197	3·60555	2·3513	53	2809	148877	7·28011	3·7563
14	196	2744	3·74166	2·4101	54	2916	157464	7·34847	3·7798
15	225	3375	3·87298	2·4662	55	3025	166375	7·4162	3·8030
16	256	4096	4·0	2·5198	56	3136	175616	7·48331	3·8259
17	289	4913	4·12311	2·5713	57	3249	185193	7·54983	3·8485
18	324	5832	4·24264	2·6207	58	3364	195112	7·61577	3·8709
19	361	6859	4·35890	2·6684	59	3481	205379	7·68115	3·8930
20	400	8000	4·47214	2·7144	60	3600	216000	7·74597	3·9149
21	441	9261	4·58258	2·7589	61	3721	226981	7·81025	3·9365
22	484	10648	4·69042	2·8020	62	3844	238328	7·87401	3·9579
23	529	12167	4·79583	2·8439	63	3969	250047	7·93725	3·9791
24	576	13824	4·89898	2·8845	64	4096	262144	8·0	4·0
25	625	15625	5·0	2·9240	65	4225	274625	8·06226	4·0207
26	676	17576	5·09902	2·9625	66	4356	287496	8·12404	4·0412
27	729	19683	5·19615	3·0	67	4489	300763	8·18535	4·0615
28	784	21952	5·29150	3·0366	68	4624	314432	8·24621	4·0817
29	841	24389	5·38516	3·0723	69	4761	328509	8·30662	4·1016
30	900	27000	5·47723	3·1072	70	4900	343000	8·36660	4·1213
31	961	29791	5·56776	3·1414	71	5041	357911	8·42615	4·1408
32	1024	32768	5·65685	3·1748	72	5184	373248	8·48528	4·1602
33	1089	35937	5·74456	3·2075	73	5329	389017	8·54400	4·1793
34	1156	39304	5·83095	3·2396	74	5476	405224	8·60233	4·1983
35	1225	42875	5·91608	3·2711	75	5625	421875	8·66025	4·2172
36	1296	46656	6·0	3·3019	76	5776	438976	8·71780	4·2358
37	1369	50653	6·08276	3·3322	77	5929	456533	8·77496	4·2543
38	1444	54872	6·16441	3·3620	78	6084	474552	8·83176	4·2727
39	1521	59319	6·245	3·3912	79	6241	493039	8·88819	4·2908
40	1600	64000	6·32456	3·4200	80	6400	512000	8·94427	4·3089

Squares, Cubes, Square Roots, and Cube Roots—*continued.*

No.	Sqre.	Cube.	Square Root.	Cube Root.	No.	Sqre.	Cube.	Square Root.	Cube Root.
81	6561	531441	9·0	4·3267	121	14641	1771561	11·0	4·9461
82	6724	551368	9·05539	4·3445	122	14884	1815848	11·04536	4·9597
83	6889	571787	9·11043	4·3621	123	15129	1860867	11·09054	4·9732
84	7056	592704	9·16515	4·3795	124	15376	1906624	11·13553	4·9866
85	7225	614125	9·21954	4·3968	125	15625	1953125	11·18034	5·0
86	7396	636056	9·27362	4·4140	126	15876	2000376	11·22497	5·0133
87	7569	658503	9·32738	4·4310	127	16129	2048383	11·26943	5·0265
88	7744	681472	9·38083	4·4480	128	16384	2097152	11·31371	5·0397
89	7921	704969	9·43398	4·4647	129	16641	2146689	11·35782	5·0528
90	8100	729000	9·48683	4·4814	130	16900	2197000	11·40188	5·0652
91	8281	753571	9·53939	4·4979	131	17161	2248091	11·44552	5·0788
92	8464	778688	9·59166	4·5144	132	17424	2299968	11·48913	5·0916
93	8649	804357	9·64365	4·5307	133	17689	2352637	11·53256	5·1045
94	8836	830584	9·69536	4·5468	134	17956	2406104	11·57584	5·1172
95	9025	857375	9·74679	4·5629	135	18225	2460375	11·61895	5·1299
96	9216	884736	9·79796	4·5789	136	18496	2515456	11·6619	5·1426
97	9409	912673	9·84886	4·5947	137	18769	2571353	11·70470	5·1551
98	9604	941192	9·89949	4·6104	138	19044	2628072	11·74734	5·1676
99	9801	970299	9·94987	4·6261	139	19321	2685619	11·78983	5·1801
100	10000	1000000	10·0	4·6416	140	19600	2744000	11·8322	5·1925
101	10201	1030301	10·04988	4·6570	141	19881	2803221	11·87434	5·2048
102	10404	1061208	10·09950	4·6723	142	20164	2863288	11·9164	5·2171
103	10609	1092727	10·14889	4·6875	143	20449	2924207	11·9583	5·2293
104	10816	1124864	10·19804	4·7027	144	20736	2985984	12·0	5·2415
105	11025	1157625	10·24695	4·7177	145	21025	3048625	12·0416	5·2536
106	11236	1191016	10·29563	4·7326	146	21316	3112136	12·08305	5·2656
107	11449	1225043	10·34408	4·7475	147	21609	3176523	12·12436	5·2776
108	11664	1259712	10·39230	4·7622	148	21904	3241792	12·16553	5·2896
109	11881	1295029	10·44031	4·7769	149	22201	3307949	12·20656	5·3015
110	12100	1331000	10·48809	4·7914	150	22500	3375000	12·24745	5·3133
111	12321	1367631	10·53565	4·8059	151	22801	3442951	12·28821	5·3251
112	12544	1404928	10·58301	4·8203	152	23104	3511808	12·32883	5·3368
113	12769	1442897	10·63015	4·8346	153	23409	3581577	12·36932	5·3485
114	12996	1481544	10·67708	4·8488	154	23716	3652264	12·40967	5·3601
115	13225	1520875	10·72381	4·8629	155	24025	3723875	12·44990	5·3717
116	13456	1560896	10·77033	4·877	156	24336	3796416	12·49000	5·3832
117	13689	1601613	10·81665	4·8910	157	24649	3869893	12·52996	5·3947
118	13924	1643032	10·86278	4·9049	158	24964	3944312	12·56981	5·4061
119	14161	1685159	10·90871	4·9187	159	25281	4019679	12·60952	5·4175
120	14400	1728000	10·95445	4·9324	160	25600	4096000	12·64911	5·4288

Squares, Cubes, Square Roots, and Cube Roots—*continued.*

No.	Sqre.	Cube.	Square Root.	Cube Root.	No.	Sqre.	Cube.	Square Root.	Cube Root.
161	25921	4173281	12·68858	5·4401	201	40401	8120601	14·1774	5·8578
162	26244	4251528	12·72792	5·4514	202	40804	8242408	14·2127	5·8675
163	26569	4330747	12·76715	5·4626	203	41209	8365427	14·2478	5·8771
164	26896	4410944	12·80625	5·4737	204	41616	8489664	14·2829	5·8868
165	27225	4492125	12·84523	5·4848	205	42025	8615125	14·3178	5·8964
166	27556	4574296	12·88410	5·4959	206	42436	8741816	14·3527	5·9059
167	27889	4657463	12·92285	5·5069	207	42849	8869743	14·3875	5·9155
168	28224	4741632	12·96148	5·5178	208	43264	8998912	14·4222	5·9250
169	28561	4826809	13·00000	5·5288	209	43681	9129329	14·4568	5·9345
170	28900	4913000	13·03840	5·5397	210	44100	9261000	14·4914	5·9439
171	29241	5000211	13·07670	5·5505	211	44521	9393931	14·5258	5·9533
172	29584	5088448	13·11488	5·5613	212	44944	9528128	14·5602	5·9627
173	29929	5177717	13·15295	5·5721	213	45369	9663597	14·5945	5·9721
174	30276	5268024	13·19091	5·5828	214	45796	9800344	14·6287	5·9814
175	30625	5359375	13·22876	5·5934	215	46225	9938375	14·6629	5·9907
176	30976	5451776	13·26650	5·6041	216	46656	10077696	14·6969	6·0
177	31329	5545233	13·30413	5·6147	217	47089	10218313	14·7309	6·0092
178	31684	5639752	13·34166	5·6252	218	47524	10360232	14·7648	6·0185
179	32041	5735339	13·37909	5·6357	219	47961	10503459	14·7986	6·0277
180	32400	5832000	13·41641	5·6462	220	48400	10648000	14·8324	6·0368
181	32761	5929741	13·45362	5·6567	221	48841	10793861	14·8661	6·0459
182	33124	6028568	13·49074	5·6671	222	49284	10941048	14·8997	6·0550
183	33489	6128487	13·52775	5·6774	223	49729	11089567	14·9332	6·0641
184	33856	6229504	13·56466	5·6877	224	50176	11239424	14·9666	6·0732
185	34225	6331625	13·60147	5·6980	225	50625	11390625	15·0	6·0822
186	34596	6434856	13·63818	5·7083	226	51076	11543176	15·0333	6·0912
187	34969	6539203	13·67479	5·7185	227	51529	11697083	15·0665	6·1002
188	35344	6644672	13·71131	5·7287	228	51984	11852352	15·0997	6·1091
189	35721	6751269	13·74773	5·7388	229	52441	12008989	15·1327	6·1180
190	36100	6859000	13·78405	5·7489	230	52900	12167000	15·1658	6·1269
191	36481	6967871	13·82028	5·7590	231	53361	12326391	15·1987	6·1358
192	36864	7077888	13·85641	5·7689	232	53824	12487168	15·2315	6·1446
193	37249	7189057	13·89244	5·7790	233	54289	12649337	15·2643	6·1534
194	37636	7301384	13·92839	5·7890	234	54756	12812904	15·2971	6·1622
195	38025	7414875	13·96424	5·7988	235	55225	12977875	15·3297	6·1710
196	38416	7529536	14·000	5·8088	236	55696	13144256	15·3623	6·1797
197	38809	7645373	14·03567	5·8186	237	56169	13312053	15·3948	6·1885
198	39204	7762392	14·07125	5·8285	238	56644	13481272	15·4272	6·1972
199	39601	7880599	14·10674	5·8383	239	57121	13651919	15·4596	6·2058
200	40000	8000000	14·14214	5·8480	240	57600	13824000	15·4919	6·2145

No.	Sqre.	Cube.	Square Root.	Cube Root.	No.	Square.	Cube.	Square Root.	Cube Root.
241	58081	13997521	15·5242	6·2231	281	78961	22188041	16·7631	6·550
242	58564	14172488	15·5563	6·2317	282	79524	22425768	16·7929	6·558
243	59049	14348907	15·5885	6·2403	283	80089	22665187	16·8226	6·565
244	59536	14526784	15·6205	6·2488	284	80656	22906304	16·8523	6·573
245	60025	14706125	15·6525	6·2573	285	81225	23149125	16·8819	6·581
246	60516	14886936	15·6844	6·2658	286	81796	23393656	16·9115	6·589
247	61009	15069223	15·7162	6·2743	287	82369	23639903	16·9411	6·596
248	61504	15252992	15·7480	6·2828	288	82944	23887872	16·9706	6·604
249	62001	15438249	15·7797	6·2912	289	83521	24137569	17·0	6·611
250	62500	15625000	15·8114	6·2996	290	84100	24389000	17·0294	6·619
251	63001	15813251	15·8430	6·3080	291	84681	24642171	17·0587	6·627
252	63504	16003008	15·8745	6·3164	292	85264	24897088	17·0880	6·634
253	64009	16194277	15·9060	6·3247	293	85849	25153757	17·1172	6·642
254	64516	16387064	15·9374	6·3330	294	86436	25412184	17·1464	6·649
255	65025	16581375	15·9687	6·3413	295	87025	25672375	17·1756	6·657
256	65536	16777216	16·0	6·3496	296	87616	25934336	17·2047	6·664
257	66049	16974593	16·0312	6·3579	297	88209	26198073	17·2337	6·672
258	66564	17173512	16·0624	6·3661	298	88804	26463592	17·2627	6·679
259	67081	17373979	16·0935	6·3743	299	89401	26730899	17·2916	6·687
260	67600	17576000	16·1245	6·3825	300	90000	27000000	17·3205	6·694
261	68121	17779581	16·1555	6·3907	301	90601	27270901	17·3494	6·702
262	68644	17984728	16·1864	6·3988	302	91204	27543608	17·3781	6·709
263	69169	18191447	16·2173	6·4070	303	91809	27818127	17·4069	6·717
264	69696	18399744	16·2481	6·4151	304	92416	28094464	17·4356	6·724
265	70225	18609625	16·2788	6·4232	305	93025	28372625	17·4642	6·731
266	70756	18821096	16·3095	6·4312	306	93636	28652616	17·4929	6·739
267	71289	19034163	16·3401	6·4393	307	94249	28934443	17·5214	6·746
268	71824	19248832	16·3707	6·4473	308	94864	29218112	17·5499	6·753
269	72361	19465109	16·4012	6·4553	309	95481	29503629	17·5784	6·761
270	72900	19683000	16·4317	6·4633	310	96100	29791000	17·6068	6·768
271	73441	19902511	16·4621	6·4713	311	96721	30080231	17·6352	6·775
272	73984	20123648	16·4924	6·4792	312	97344	30371328	17·6635	6·782
273	74529	20346417	16·5227	6·4872	313	97969	30664297	17·6918	6·790
274	75076	20570824	16·5529	6·4951	314	98596	30959144	17·7200	6·797
275	75625	20796875	16·5831	6·5030	315	99225	31255875	17·7482	6·804
276	76176	21024576	16·6132	6·5108	316	99856	31554496	17·7764	6·811
277	76729	21253933	16·6433	6·5187	317	100489	31855013	17·8045	6·818
278	77284	21484952	16·6733	6·5265	318	101124	32157432	17·8326	6·826
279	77841	21717639	16·7033	6·5343	319	101761	32461759	17·8606	6·833
280	78400	21952000	16·7332	6·5421	320	102400	32768000	17·8885	6·840

SQUARES, CUBES, SQUARE ROOTS, AND CUBE ROOTS—*continued.*

No.	Square.	Cube.	Square Root.	Cube Root.	No.	Square.	Cube.	Square Root.	Cube Root.
321	103041	33076161	17·9165	6·847	361	130321	47045881	19·0	7·120
322	103684	33386248	17·9444	6·854	362	131044	47437928	19·0263	7·127
323	104329	33698267	17·9722	6·861	363	131769	47832147	19·0526	7·133
324	104976	34012224	18·0	6·868	364	132496	48228544	19·0788	7·140
325	105625	34328125	18·0278	6·875	365	133225	48627125	19·1050	7·147
326	106276	34645976	18·0555	6·882	366	133956	49027896	19·1311	7·153
327	106929	34965783	18·0831	6·889	367	134689	49430863	19·1572	7·160
328	107584	35287552	18·1108	6·896	368	135424	49836032	19·1833	7·166
329	108241	35611289	18·1384	6·903	369	136161	50243409	19·2094	7·173
330	108900	35937000	18·1659	6·910	370	136900	50653000	19·2354	7·179
331	109561	36264691	18·1934	6·917	371	137641	51064811	19·2614	7·186
332	110224	36594368	18·2209	6·924	372	138384	51478848	19·2873	7·192
333	110889	36926037	18·2483	6·931	373	139129	51895117	19·3132	7·198
334	111556	37259704	18·2757	6·938	374	139876	52313624	19·3391	7·205
335	112225	37595375	18·3030	6·945	375	140625	52734375	19·3649	7·211
336	112896	37933056	18·3303	6·952	376	141376	53157376	19·3907	7·218
337	113569	38272753	18·3576	6·959	377	142129	53582633	19·4165	7·224
338	114244	38614472	18·3848	6·966	378	142884	54010152	19·4422	7·230
339	114921	38958219	18·4120	6·973	379	143641	54439939	19·4679	7·237
340	115600	39304000	18·4391	6·980	380	144400	54872000	19·4936	7·243
341	116281	39651821	18·4662	6·986	381	145161	55306341	19·5192	7·249
342	116964	40001688	18·4932	6·993	382	145924	55742968	19·5448	7·256
343	117649	40353607	18·5203	7·0	383	146689	56181887	19·5704	7·262
344	118336	40707584	18·5472	7·007	384	147456	56623104	19·5959	7·268
345	119025	41063625	18·5742	7·014	385	148225	57066625	19·6214	7·275
346	119716	41421736	18·6011	7·020	386	148996	57512456	19·6469	7·281
347	120409	41781923	18·6279	7·027	387	149769	57960603	19·6723	7·287
348	121104	42144192	18·6548	7·034	388	150544	58411072	19·6977	7·294
349	121801	42508549	18·6815	7·041	389	151321	58863869	19·7231	7·300
350	122500	42875000	18·7083	7·047	390	152100	59319000	19·7484	7·306
351	123201	43243551	18·7350	7·054	391	152881	59776471	19·7737	7·312
352	123904	43614208	18·7617	7·061	392	153664	60236288	19·7990	7·319
353	124609	43986977	18·7883	7·067	393	154449	60698457	19·8242	7·325
354	125316	44361864	18·8149	7·074	394	155236	61162984	19·8494	7·331
355	126025	44738875	18·8414	7·081	395	156025	61629875	19·8746	7·337
356	126736	45118016	18·8680	7·087	396	156816	62099136	19·8997	7·343
357	127449	45499293	18·8944	7·094	397	157609	62570773	19·9249	7·350
358	128164	45882712	18·9209	7·101	398	158404	63044792	19·9499	7·356
359	128881	46268279	18·9473	7·107	399	159201	63521199	19·9750	7·362

No.	Square.	Cube.	Square Root.	Cube Root.	No.	Square.	Cube.	Square Root.	Cube Root.
401	160801	64481201	20·0250	7·374	441	194481	85766121	21·0	7·612
402	161604	64964808	20·0499	7·380	442	195364	86350888	21·024	7·617
403	162409	65450827	20·0749	7·386	443	196249	86938307	21·048	7·623
404	163216	65939264	20·0998	7·393	444	197136	87528384	21·071	7·629
405	164025	66430125	20·1246	7·399	445	198025	88121125	21·095	7·635
406	164836	66923416	20·1494	7·405	446	198916	88716536	21·119	7·640
407	165649	67419143	20·1742	7·411	447	199809	89314623	21·142	7·646
408	166464	67917312	20·1990	7·417	448	200704	89915392	21·166	7·652
409	167281	68417929	20·2237	7·423	449	201601	90518849	21·190	7·657
410	168100	68921000	20·2485	7·429	450	202500	91125000	21·213	7·663
411	168921	69426531	20·2731	7·435	451	203401	91733851	21·237	7·669
412	169744	69934528	20·2978	7·441	452	204304	92345408	21·260	7·674
413	170569	70444997	20·3224	7·447	453	205209	92959677	21·284	7·680
414	171396	70957944	20·3470	7·453	454	206116	93576664	21·307	7·686
415	172225	71473375	20·3715	7·459	455	207025	94196375	21·331	7·691
416	173056	71991296	20·3961	7·465	456	207936	94818816	21·354	7·697
417	173889	72511713	20·4206	7·471	457	208849	95443993	21·378	7·703
418	174724	73034632	20·4450	7·477	458	209764	96071912	21·401	7·708
419	175561	73560059	20·4695	7·483	459	210681	96702579	21·424	7·714
420	176400	74088000	20·4939	7·489	460	211600	97336000	21·448	7·719
421	177241	74618461	20·5183	7·495	461	212521	97972181	21·471	7·725
422	178084	75151448	20·5426	7·501	462	213444	98611128	21·494	7·731
423	178929	75686967	20·5670	7·507	463	214369	99252847	21·517	7·736
424	179776	76225024	20·5913	7·513	464	215296	99897344	21·541	7·742
425	180625	76765625	20·6155	7·518	465	216225	100544625	21·564	7·747
426	181476	77308776	20·6398	7·524	466	217156	101194696	21·587	7·753
427	182329	77854483	20·6640	7·530	467	218089	101847563	21·610	7·758
428	183184	78402752	20·6882	7·536	468	219024	102503232	21·633	7·764
429	184041	78953589	20·7123	7·542	469	219961	103161709	21·656	7·769
430	184900	79507000	20·7364	7·548	470	220900	103823000	21·679	7·775
431	185761	80062991	20·7605	7·554	471	221841	104487111	21·703	7·780
432	186624	80621568	20·7846	7·560	472	222784	105154048	21·726	7·786
433	187489	81182737	20·8087	7·565	473	223729	105823817	21·749	7·791
434	188356	81746504	20·8327	7·571	474	224676	106496424	21·772	7·797
435	189225	82312875	20·8567	7·577	475	225625	107171875	21·794	7·802
436	190096	82881856	20·8806	7·583	476	226576	107850176	21·817	7·808
437	190969	83453453	20·9045	7·589	477	227529	108531333	21·840	7·813
438	191844	84027672	20·9284	7·594	478	228484	109215352	21·863	7·819
439	192721	84604519	20·9523	7·600	479	229441	109902239	21·886	7·824
440	193600	85184000	20·9762	7·606	480	230400	110592000	21·909	7·830

SQUARES, CUBES, SQUARE ROOTS, AND CUBE ROOTS—*continued.*

No.	Square.	Cube.	Square Root.	Cube Root.	No.	Square.	Cube.	Square Root.	Cube Root.
481	231361	111284641	21·932	7·835	521	271441	141420761	22·825	8·047
482	232324	111980168	21·954	7·841	522	272484	142236648	22·847	8·052
483	233289	112678587	21·977	7·846	523	273529	143055667	22·869	8·057
484	234256	113379904	22·0	7·851	524	274576	143877824	22·891	8·062
485	235225	114084125	22·023	7·857	525	275625	144703125	22·913	8·067
486	236196	114791256	22·045	7·862	526	276676	145531576	22·935	8·072
487	237169	115501303	22·068	7·868	527	277729	146363183	22·956	8·077
488	238144	116214272	22·091	7·873	528	278784	147197952	22·978	8·082
489	239121	116930169	22·113	7·878	529	279841	148035889	23·0	8·088
490	240100	117649000	22·136	7·884	530	280900	148877000	23·022	8·093
491	241081	118370771	22·159	7·889	531	281961	149721291	23·043	8·098
492	242064	119095488	22·181	7·894	532	283024	150568768	23·065	8·103
493	243049	119823157	22·204	7·900	533	284089	151419437	23·087	8·108
494	244036	120553784	22·226	7·905	534	285156	152273304	23·108	8·113
495	245025	121287375	22·249	7·910	535	286225	153130375	23·130	8·118
496	246016	122023936	22·271	7·916	536	287296	153990656	23·152	8·123
497	247009	122763473	22·293	7·921	537	288369	154854153	23·173	8·128
498	248004	123505992	22·316	7·926	538	289444	155720872	23·195	8·133
499	249001	124251499	22·338	7·932	539	290521	156590819	23·216	8·138
500	250000	125000000	22·361	7·937	540	291600	157464000	23·238	8·143
501	251001	125751501	22·383	7·942	541	292681	158340421	23·259	8·148
502	252004	126506008	22·405	7·948	542	293764	159220088	23·281	8·153
503	253009	127263527	22·428	7·953	543	294849	160103007	23·302	8·158
504	254016	128024064	22·450	7·958	544	295936	160989184	23·324	8·163
505	255025	128787625	22·472	7·963	545	297025	161878625	23·345	8·168
506	256036	129554216	22·494	7·969	546	298116	162771336	23·367	8·173
507	257049	130323843	22·517	7·974	547	299209	163667323	23·388	8·178
508	258064	131096512	22·539	7·979	548	300304	164566592	23·409	8·183
509	259081	131872229	22·561	7·984	549	301401	165469149	23·431	8·188
510	260100	132651000	22·583	7·990	550	302500	166375000	23·452	8·193
511	261121	133432831	22·605	7·995	551	303601	167284151	23·473	8·198
512	262144	134217728	22·627	8·0	552	304704	168196608	23·495	8·203
513	263169	135005697	22·649	8·005	553	305809	169112377	23·516	8·208
514	264196	135796744	22·672	8·010	554	306916	170031464	23·537	8·213
515	265225	136590875	22·694	8·016	555	308025	170953875	23·558	8·218
516	266256	137388096	22·716	8·021	556	309136	171879616	23·580	8·223
517	267289	138188413	22·738	8·026	557	310249	172808693	23·601	8·228
518	268324	138991832	22·760	8·031	558	311364	173741112	23·622	8·233

No.	Square.	Cube.	Square Root.	Cube Root.	No.	Square.	Cube.	Square Root.	Cube Root.
561	314721	176558481	23·685	8·247	601	361201	217081801	24·515	8·439
562	315844	177504328	23·707	8·252	602	362404	218167208	24·536	8·444
563	316969	178453547	23·728	8·257	603	363609	219256227	24·556	8·448
564	318096	179406144	23·749	8·262	604	364816	220348864	24·576	8·453
565	319225	180362125	23·770	8·267	605	366025	221445125	24·597	8·458
566	320356	181321496	23·791	8·272	606	367236	222545016	24·617	8·462
567	321489	182284263	23·812	8·277	607	368449	223648543	24·637	8·467
568	322624	183250432	23·833	8·282	608	369664	224755712	24·658	8·472
569	323761	184220009	23·854	8·286	609	370881	225866529	24·678	8·476
570	324900	185193000	23·875	8·291	610	372100	226981000	24·698	8·481
571	326041	186169411	23·896	8·296	611	373321	228099131	24·718	8·486
572	327184	187149248	23·917	8·301	612	374544	229220928	24·739	8·490
573	328329	188132517	23·937	8·306	613	375769	230346397	24·759	8·495
574	329476	189119224	23·958	8·311	614	376996	231475544	24·779	8·499
575	330625	190109375	23·979	8·316	615	378225	232608375	24·799	8·504
576	331776	191102976	24·0	8·320	616	379456	233744896	24·819	8·509
577	332929	192100033	24·021	8·325	617	380689	234885113	24·839	8·513
578	334084	193100552	24·042	8·330	618	381924	236029032	24·860	8·518
579	335241	194104539	24·062	8·335	619	383161	237176659	24·880	8·522
580	336400	195112000	24·083	8·340	620	384400	238328000	24·900	8·527
581	337561	196122941	24·104	8·344	621	385641	239483061	24·920	8·532
582	338724	197137368	24·125	8·349	622	386884	240641848	24·940	8·536
583	339889	198155287	24·145	8·354	623	388129	241804367	24·960	8·541
584	341056	199176704	24·166	8·359	624	389376	242970624	24·980	8·545
585	342225	200201625	24·187	8·363	625	390625	244140625	25·0	8·550
586	343396	201230056	24·207	8·368	626	391876	245314376	25·020	8·554
587	344569	202262003	24·228	8·373	627	393129	246491883	25·040	8·559
588	345744	203297472	24·249	8·378	628	394384	247673152	25·060	8·564
589	346921	204336469	24·269	8·382	629	395641	248858189	25·080	8·568
590	348100	205379000	24·290	8·387	630	396900	250047000	25·100	8·573
591	349281	206425071	24·310	8·392	631	398161	251239591	25·120	8·577
592	350464	207474688	24·331	8·397	632	399424	252435968	25·140	8·582
593	351649	208527857	24·352	8·401	633	400689	253636137	25·159	8·586
594	352836	209584584	24·372	8·406	634	401956	254840104	25·179	8·591
595	354025	210644875	24·393	8·411	635	403225	256047875	25·199	8·595
596	355216	211708736	24·413	8·416	636	404496	257259456	25·219	8·600
597	356409	212776173	24·434	8·420	637	405769	258474853	25·239	8·604
598	357604	213847192	24·454	8·425	638	407044	259694072	25·259	8·609
599	358801	214921799	24·474	8·430	639	408321	260917119	25·278	8·613
600	360000	216000000	24·495	8·434	640	409600	262144000	25·298	8·618

SQUARES, CUBES, SQUARE ROOTS, AND CUBE ROOTS—*continued.*

No.	Square.	Cube.	Square Root.	Cube Root.	No.	Square.	Cube.	Square Root.	Cube Root.
641	410881	263374721	25·318	8·622	681	463761	315821241	26·096	8·798
642	412164	264609288	25·338	8·627	682	465124	317214568	26·115	8·802
643	413449	265847707	25·357	8·631	683	466489	318611987	26·134	8·807
644	414736	267089984	25·377	8·636	684	467856	320013504	26·153	8·811
645	416025	268336125	25·397	8·640	685	469225	321419125	26·172	8·815
646	417316	269586136	25·417	8·645	686	470596	322828856	26·192	8·819
647	418609	270840023	25·436	8·649	687	471969	324242703	26·211	8·824
648	419904	272097792	25·456	8·653	688	473344	325660672	26·230	8·828
649	421201	273359449	25·475	8·658	689	474721	327082769	26·249	8·832
650	422500	274625000	25·495	8·662	690	476100	328509000	26·268	8·837
651	423801	275894451	25·515	8·667	691	477481	329939371	26·287	8·841
652	425104	277167808	25·534	8·671	692	478864	331373888	26·306	8·845
653	426409	278445077	25·554	8·676	693	480249	332812557	26·325	8·849
654	427716	279726264	25·573	8·680	694	481636	334255384	26·344	8·854
655	429025	281011375	25·593	8·685	695	483025	335702375	26·363	8·858
656	430336	282300416	25·612	8·689	696	484416	337153536	26·382	8·862
657	431649	283593393	25·632	8·693	697	485809	338608873	26·401	8·866
658	432964	284890312	25·652	8·698	698	487204	340068392	26·420	8·871
659	434281	286191179	25·671	8·702	699	488601	341532099	26·439	8·875
660	435600	287496000	25·690	8·707	700	490000	343000000	26·458	8·879
661	436921	288804781	25·710	8·711	701	491401	344472101	26·476	8·883
662	438244	290117528	25·729	8·715	702	492804	345948408	26·495	8·887
663	439569	291434247	25·749	8·720	703	494209	347428927	26·514	8·892
664	440896	292754944	25·768	8·724	704	495616	348913664	26·533	8·896
665	442225	294079625	25·788	8·729	705	497025	350402625	26·552	8·900
666	443556	295408296	25·807	8·733	706	498436	351895816	26·571	8·904
667	444889	296740963	25·826	8·737	707	499849	353393243	26·589	8·909
668	446224	298077632	25·846	8·742	708	501264	354894912	26·608	8·913
669	447561	299418309	25·865	8·746	709	502681	356400829	26·627	8·917
670	448900	300763000	25·884	8·750	710	504100	357911000	26·646	8·921
671	450241	302111711	25·904	8·755	711	505521	359425431	26·665	8·925
672	451584	303464448	25·923	8·759	712	506944	360944128	26·683	8·929
673	452929	304821217	25·942	8·763	713	508369	362467097	26·702	8·934
674	454276	306182024	25·962	8·768	714	509796	363994344	26·721	8·938
675	455625	307546875	25·981	8·772	715	511225	365525875	26·739	8·942
676	456976	308915776	26·0	8·776	716	512656	367061696	26·758	8·946
677	458329	310288733	26·019	8·781	717	514089	368601813	26·777	8·950
678	459684	311665752	26·038	8·785	718	515524	370146232	26·796	8·955
679	461041	313046839	26·058	8·789	719	516961	371694959	26·814	8·959

SQUARES, CUBES, SQUARE ROOTS, AND CUBE ROOTS—*continued.*

No.	Square.	Cube.	Square Root.	Cube Root.	No.	Square.	Cube.	Square Root.	Cube Root.
721	519841	374805361	26·851	8·967	761	579121	440711081	27·586	9·130
722	521284	376367048	26·870	8·971	762	580644	442450728	27·604	9·134
723	522729	377933067	26·889	8·975	763	582169	444194947	27·622	9·138
724	524176	379503424	26·907	8·979	764	583696	445943744	27·641	9·142
725	525625	381078125	26·926	8·983	765	585225	447697125	27·659	9·146
726	527076	382657176	26·944	8·988	766	586756	449455096	27·677	9·150
727	528529	384240583	26·963	8·992	767	588289	451217663	27·695	9·154
728	529984	385828352	26·981	8·996	768	589824	452984832	27·713	9·158
729	531441	387420489	27·0	9·0	769	591361	454756609	27·731	9·162
730	532900	389017000	27·019	9·004	770	592900	456533000	27·749	9·166
731	534361	390617891	27·037	9·008	771	594441	458314011	27·767	9·170
732	535824	392223168	27·055	9·012	772	595984	460099648	27·785	9·174
733	537289	393832837	27·074	9·016	773	597529	461889917	27·803	9·178
734	538756	395446904	27·092	9·021	774	599076	463684824	27·821	9·181
735	540225	397065375	27·111	9·025	775	600625	465484375	27·839	9·185
736	541696	398688256	27·129	9·029	776	602176	467288576	27·857	9·189
737	543169	400315553	27·148	9·033	777	603729	469097433	27·875	9·193
738	544644	401947272	27·166	9·037	778	605284	470910952	27·893	9·197
739	546121	403583419	27·185	9·041	779	606841	472729139	27·911	9·201
740	547600	405224000	27·203	9·045	780	608400	474552000	27·928	9·205
741	549081	406869021	27·221	9·049	781	609961	476379541	27·946	9·209
742	550564	408518488	27·240	9·053	782	611524	478211768	27·964	9·213
743	552049	410172407	27·258	9·057	783	613089	480048687	27·982	9·217
744	553536	411830784	27·276	9·061	784	614656	481890304	28·0	9·221
745	555025	413493625	27·295	9·065	785	616225	483736625	28·018	9·225
746	556516	415160936	27·313	9·069	786	617796	485587656	28·036	9·229
747	558009	416832723	27·331	9·073	787	619369	487443403	28·054	9·233
748	559504	418508992	27·350	9·078	788	620944	489303872	28·071	9·237
749	561001	420189749	27·368	9·082	789	622521	491169069	28·089	9·240
750	562500	421875000	27·386	9·086	790	624100	493039000	28·107	9·244
751	564001	423564751	27·404	9·090	791	625681	494913671	28·125	9·248
752	565504	425259008	27·423	9·094	792	627264	496793088	28·142	9·252
753	567009	426957777	27·441	9·098	793	628849	498677257	28·160	9·256
754	568516	428661064	27·459	9·102	794	630436	500566184	28·178	9·260
755	570025	430368875	27·477	9·106	795	632025	502459875	28·196	9·264
756	571536	432081216	27·495	9·110	796	633616	504358336	28·213	9·268
757	573049	433798093	27·514	9·114	797	635209	506261573	28·231	9·272
758	574564	435519512	27·532	9·118	798	636804	508169592	28·249	9·275
759	576081	437245479	27·550	9·122	799	638401	510082399	28·267	9·279
760	577600	438976000	27·568	9·126	800	640000	512000000	28·284	9·283

SQUARES, CUBES, SQUARE ROOTS, AND CUBE ROOTS—*continued.*

No.	Square.	Cube.	Square Root.	Cube Root.	No.	Square.	Cube.	Square Root.	Cube Root.
801	641601	513922401	28·302	9·287	841	707281	594823321	29·0	9·439
802	643204	515849608	28·320	9·291	842	708964	596947688	29·017	9·443
803	644809	517781627	28·337	9·295	843	710649	599077107	29·034	9·447
804	646416	519718464	28·355	9·299	844	712336	601211584	29·052	9·450
805	648025	521660125	28·373	9·302	845	714025	603351125	29·069	9·454
806	649636	523606616	28·390	9·306	846	715716	605495736	29·086	9·458
807	651249	525557943	28·408	9·310	847	717409	607645423	29·103	9·462
808	652864	527514112	28·425	9·314	848	719104	609800192	29·120	9·465
809	654481	529475129	28·443	9·318	849	720801	611960049	29·138	9·469
810	656100	531441000	28·460	9·322	850	722500	614125000	29·155	9·473
811	657721	533411731	28·478	9·326	851	724201	616295051	29·172	9·476
812	659344	535387328	28·496	9·329	852	725904	618470208	29·189	9·480
813	660969	537367797	28·513	9·333	853	727609	620650477	29·206	9·484
814	662596	539353144	28·531	9·337	854	729316	622835864	29·223	9·488
815	664225	541343375	28·548	9·341	855	731025	625026375	29·240	9·491
816	665856	543338496	28·566	9·345	856	732736	627222016	29·257	9·495
817	667489	545338513	28·583	9·348	857	734449	629422793	29·275	9·499
818	669124	547343432	28·601	9·352	858	736164	631628712	29·292	9·502
819	670761	549353259	28·618	9·356	859	737881	633839779	29·309	9·506
820	672400	551368000	28·636	9·360	860	739600	636056000	29·326	9·510
821	674041	553387661	28·653	9·364	861	741321	638277381	29·343	9·513
822	675684	555412248	28·671	9·367	862	743044	640503928	29·360	9·517
823	677329	557441767	28·688	9·371	863	744769	642735647	29·377	9·521
824	678976	559476224	28·705	9·375	864	746496	644972544	29·394	9·524
825	680625	561515625	28·723	9·379	865	748225	647214625	29·411	9·528
826	682276	563559976	28·740	9·383	866	749956	649461896	29·428	9·532
827	683929	565609283	28·758	9·386	867	751689	651714363	29·445	9·535
828	685584	567663552	28·775	9·390	868	753424	653972032	29·462	9·539
829	687241	569722789	28·792	9·394	869	755161	656234909	29·479	9·543
830	688900	571787000	28·810	9·398	870	756900	658503000	29·496	9·546
831	690561	573856191	28·827	9·402	871	758641	660776311	29·513	9·550
832	692224	575930368	28·844	9·405	872	760384	663054848	29·530	9·554
833	693889	578009537	28·862	9·409	873	762129	665338617	29·547	9·557
834	695556	580093704	28·879	9·413	874	763876	667627624	29·563	9·561
835	697225	582182875	28·896	9·417	875	765625	669921875	29·580	9·565
836	698896	584277056	28·914	9·420	876	767376	672221376	29·597	9·568
837	700569	586376253	28·931	9·424	877	769129	674526133	29·614	9·572
838	702244	588480472	28·948	9·428	878	770884	676836152	29·631	9·576
839	703921	590589719	28·965	9·432	879	772641	679151439	29·648	9·579
840	705600	592704000	28·983	9·435	880	774400	681472000	29·665	9·583

Squares, Cubes, Square Roots, and Cube Roots—*continued.*

No.	Square.	Cube.	Square Root.	Cube Root.	No.	Square.	Cube.	Square Root.	Cube Root.
881	776161	683797841	29·682	9·586	921	848241	781229961	30·348	9·729
882	777924	686128968	29·698	9·590	922	850084	783777448	30·364	9·733
883	779689	688465387	29·715	9·594	923	851929	786330467	30·381	9·736
884	781456	690807104	29·732	9·597	924	853776	788889024	30·397	9·740
885	783225	693154125	29·749	9·601	925	855625	791453125	30·414	9·743
886	784996	695506456	29·766	9·605	926	857476	794022776	30·430	9·747
887	786769	697864103	29·783	9·608	927	859329	796597983	30·447	9·750
888	788544	700227072	29·799	9·612	928	861184	799178752	30·463	9·754
889	790321	702595369	29·816	9·615	929	863041	801765089	30·479	9·757
890	792100	704969000	29·833	9·619	930	864900	804357000	30·496	9·761
891	793881	707347971	29·850	9·623	931	866761	806954491	30·512	9·764
892	795664	709732288	29·866	9·626	932	868624	809557568	30·529	9·768
893	797449	712121957	29·883	9·63[illegible]	933	870489	812166237	30·545	9·771
894	799236	714516984	29·900	9·633	934	872356	814780504	30·561	9·775
895	801025	716917375	29·917	9·637	935	874225	817400375	30·578	9·778
896	802816	719323136	29·933	9·641	936	876096	820025856	30·594	9·782
897	804609	721734273	29·950	9·644	937	877969	822656953	30·610	9·785
898	806404	724150792	29·966	9·648	938	879844	825293672	30·627	9·789
899	808201	726572699	29·983	9·651	939	881721	827936019	30·643	9·792
900	810000	729000000	30·0	9·655	940	883600	830584000	30·659	9·796
901	811801	731432701	30·017	9·658	941	885481	833237621	30·676	9·799
902	813604	733870808	30·033	9·662	942	887364	835896888	30·692	9·803
903	815409	736314327	30·050	9·666	943	889249	838561807	30·708	9·806
904	817216	738763264	30·067	9·669	944	891136	841232384	30·725	9·810
905	819025	741217625	30·083	9·673	945	893025	843908625	30·741	9·813
906	820836	743677416	30·100	9·676	946	894916	846590536	30·757	9·817
907	822649	746142643	30·116	9·680	947	896809	849278123	30·773	9·820
908	824464	748613312	30·133	9·683	948	898704	851971392	30·790	9·824
909	826281	751089429	30·150	9·687	949	900601	854670349	30·806	9·827
910	828100	753571000	30·166	9·691	950	902500	857375000	30·822	9·830
911	829921	756058031	30·183	9·694	951	904401	860085351	30·838	9·834
912	831744	758550528	30·199	9·698	952	906304	862801408	30·854	9·837
913	833569	761048497	30 216	9·701	953	908209	865523177	30·871	9·841
914	835396	763551944	30·232	9·705	954	910116	868250664	30·887	9·844
915	837225	766060875	30·249	9·708	955	912025	870983875	30·903	9·848
916	839056	768575296	30·265	9·712	956	913936	873722816	30·919	9·851
917	840889	771095213	30·282	9·715	957	915849	876467493	30·935	9·855
918	842724	773620632	30·299	9·719	958	917764	879217912	30·952	9·858
919	844561	776151559	30·315	9·722	959	919681	881974079	30·968	9·861
920	846400	778688000	30·331	9·726	960	921600	884736000	30·984	9·865

Squares, Cubes, Square Roots, and Cube Roots—*continued.*

No.	Square.	Cube.	Square Root.	Cube Root.	No.	Square.	Cube.	Square Root.	Cube Root.
961	923521	887503681	31·0	9·868	981	962361	944076141	31·321	9·936
962	925444	890277128	31·016	9·872	982	964324	946966168	31·337	9·940
963	927369	893056347	31·032	9·875	983	966289	949862087	31·353	9·943
964	929296	895841344	31·048	9·879	984	968256	952763904	31·369	9·946
965	931225	898632125	31·064	9·882	985	970225	955671625	31·385	9·950
966	933156	901428696	31·081	9·885	986	972196	958585256	31·401	9·953
967	935089	904231063	31·097	9·889	987	974169	961504803	31·417	9·956
968	937024	907039232	31·113	9·892	988	976144	964430272	31·432	9·960
969	938961	909853209	31·129	9·896	989	978121	967361669	31·448	9·963
970	940900	912673000	31·145	9·899	990	980100	970299000	31·464	9·967
971	942841	915498611	31·161	9·902	991	982081	973242271	31·480	9·970
972	944784	918330048	31·177	9·906	992	984064	976191488	31·496	9·973
973	946729	921167317	31·193	9·909	993	986049	979146657	31·512	9·977
974	948676	924010424	31·209	9·913	994	988036	982107784	31·528	9·980
975	950625	926859375	31·225	9·916	995	990025	985074875	31·544	9·983
976	952576	929714176	31·241	9·919	996	992016	988047936	31·559	9·987
977	954529	932574833	31·257	9·923	997	994009	991026973	31·575	9·990
978	956484	935441352	31·273	9·926	998	996004	994011992	31·591	9·993
979	958441	938313739	31·289	9·929	999	998001	997002999	31·607	9·997
980	960400	941192000	31·305	9·933	1000	1000000	1000000000	31·623	10·0

Table of $\frac{2}{3}$ Powers or $\sqrt[3]{N^2}$.

N.	0	1	2	3	4	5	6	7	8	9	N.
0	0	1	1·5874	2·0801	2·5198	2·9240	3·3019	3·6593	4	4·3267	0
10	4·6416	4·9461	5·2415	5·5288	5·8088	6·0822	6·3496	6·6115	6·8683	7·1204	10
20	7·3681	7·6117	7·8514	8·0876	8·3203	8·5499	8·7764	9	9·2209	9·4391	20
30	9·6549	9·8683	10·079	10·288	10·495	10·700	10·903	11·104	11·303	11·5	30
40	11·696	11·89	12·083	12·274	12·463	12·651	12·828	13·024	13·208	13·391	40
50	13·572	13·752	13·932	14·11	14·287	14·462	14·637	14·811	14·984	15·155	50
60	15·326	15·496	15·665	15·833	16	16·166	16·332	16·496	16·66	16·823	60
70	16·985	17·146	17·307	17·467	17·626	17·784	17·942	18·099	18·256	18·411	70
80	18·566	18·721	18·875	19·028	19·180	19·33	19·483	19·634	19·784	19·934	80
90	20·083	20·231	20·379	20·527	20·674	20·82	20·966	21·111	21·256	21·40	90
100	21·544	21·688	21·831	21·973	22·115	22·257	22·397	22·538	22·678	22·818	100

TABLE OF FOURTH AND FIFTH POWERS OF NUMBERS.

No.	4th Power.	5th Power.	No.	4th Power.	5th Power.	No.	4th Power.	5th Power.	No.	4th Power.	5th Power.
1	1	1	26	456,976	11,881,376	51	6,765,201	345,025,251	76	33,362,176	2,535,525,376
2	16	32	27	531,441	14,348,907	52	7,311,616	380,204,032	77	35,153,041	2,706,784,157
3	81	243	28	614,656	17,210,368	53	7,890,481	418,195,493	78	37,015,056	2,887,174,368
4	256	1,024	29	707,281	20,511,149	54	8,503,056	459,165,024	79	38,950,081	3,077,056,399
5	625	3,125	30	810,000	24,300,000	55	9,150,625	503,284,375	80	40,960,000	3,276,800,000
6	1,296	7,776	31	923,521	28,629,151	56	9,834,496	550,731,776	81	43,046,721	3,486,784,401
7	2,401	16,807	32	1,048,576	33,554,432	57	10,556,001	601,692,057	82	45,212,176	3,707,398,432
8	4,096	32,768	33	1,185,921	39,135,393	58	11,316,496	656,356,768	83	47,458,321	3,939,040,643
9	6,561	59,049	34	1,336,336	45,435,424	59	12,117,361	714,924,299	84	49,787,136	4,182,119,424
10	10,000	100,000	35	1,500,625	52,521,875	60	12,960,000	777,600,000	85	52,200,625	4,437,053,125
11	14,641	161,051	36	1,679,616	60,466,176	61	13,845,841	844,596,301	86	54,708,016	4,704,270,176
12	20,736	248,832	37	1,874,161	69,343,957	62	14,776,336	916,132,832	87	57,289,761	4,984,209,207
13	28,561	371,293	38	2,085,136	79,235,168	63	15,752,961	992,436,543	88	59,969,536	5,277,319,168
14	38,416	537,824	39	2,313,441	90,224,199	64	16,777,216	1,073,741,824	89	62,742,241	5,584,059,4[illegible]9
15	50,625	759,375	40	2,560,000	102,400,000	65	17,850,625	1,160,290,625	90	65,610,000	5,904,900,000
16	65,536	1,048,576	41	2,825,761	115,856,201	66	18,974,736	1,252,332,576	91	68,574,961	6,240,321,451
17	83,521	1,419,857	42	3,111,696	130,691,232	67	20,151,121	1,350,125,107	92	71,639,296	6,590,815,232
18	104,976	1,889,568	43	3,418,801	147,008,443	68	21,381,376	1,453,933,568	93	74,805,201	6,956,883,693
19	130,321	2,476,099	44	3,748,096	164,916,224	69	22,667,121	1,564,031,349	94	78,074,896	7,339,040,224
20	160,000	3,200,000	45	4,100,625	184,528,125	70	24,010,000	1,684,700,000	95	81,450,625	7,737,809,375
21	194,481	4,084,101	46	4,477,456	205,962,976	71	25,411,681	1,804,229,351	96	84,934,656	8,153,726,976
22	234,256	5,153,632	47	4,879,681	229,345,007	72	26,873,856	1,934,917,632	97	88,529,281	8,587,340,257
23	279,841	6,436,343	48	5,308,416	254,803,968	73	28,398,241	2,073,071,593	98	92,236,816	9,039,207,968
24	331,776	7,962,624	49	5,764,801	282,475,249	74	29,986,576	2,219,006,624	99	96,059,601	9,509 900,499
25	390,625	9,765,625	50	6,250,000	312,500,000	75	31,640,625	2,373,046,875	100	100,000,000	10,000,000,000

Reciprocals of Numbers.

No.	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	No.
0	·0	10·000	5·00000	3·33333	2·5000	2·000	1·66667	1·42857	1·25000	1·11111	0
1	1·000	·909091	·833333	·769231	·714286	·666667	·625000	·588235	·555556	·526316	1
2	·50000	·476190	·454545	·434783	·416667	·40000	·384615	·370370	·357143	·344828	2
3	·333333	·322581	·312500	·303030	·294118	·285714	·277778	·270270	·263158	·256410	3
4	·25000	·243902	·238095	·232558	·227273	·222222	·217391	·212766	·208333	·204082	4
5	·20000	·196078	·192308	·188679	·185185	·181818	·178571	·175439	·172414	·169492	5
6	·166667	·163934	·161290	·158730	·156250	·153846	·151515	·149254	·147059	·144928	6
7	·142857	·140845	·138889	·136986	·135135	·133333	·131579	·129870	·128205	·126582	7
8	·125000	·123457	·121951	·120482	·119048	·117647	·116279	·114943	·113636	·112360	8
9	·111111	·109890	·108696	·107527	·106383	·105263	·104167	·103093	·102041	·101010	9
10	·10000	·099010	·098039	·097087	·096154	·095238	·094340	·093458	·092593	·091743	10
11	·090909	·090090	·089286	·088496	·087719	·086957	·086207	·085470	·084746	·084034	11
12	·083333	·082645	·081967	·081301	·080645	·080000	·079365	·078740	·078125	·077519	12
13	·076923	·076336	·075758	·075188	·074627	·074074	·073529	·072993	·072464	·071942	13
14	·071429	·070922	·070423	·069930	·069444	·068966	·068493	·068027	·067568	·067114	14
15	·066667	·066225	·065789	·065359	·064935	·064516	·064103	·063694	·063291	·062893	15
16	·062500	·062112	·061728	·061350	·060976	·060606	·060241	·059880	·059524	·059172	16
17	·058824	·058480	·058140	·057803	·057471	·057143	·056818	·056497	·056180	·055866	17
18	·055556	·055249	·054945	·054645	·054348	·054054	·053763	·053476	·053191	·052910	18
19	·052632	·052356	·052083	·051813	·051546	·051282	·051020	·050761	·050505	·050251	19
20	·050000	·049751	·049505	·049261	·049020	·048780	·048544	·048309	·048077	·047847	20
21	·047619	·047393	·047170	·046948	·046729	·046512	·046296	·046083	·045872	·045662	21

RECIPROCALS OF NUMBERS—*continued.*

No.	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	No.
22	·045455	·045249	·045045	·044843	·044643	·044444	·044248	·044053	·043860	·043668	22
23	·043478	·043290	·043103	·042918	·042735	·042553	·042373	·042194	·042017	·041841	23
24	·041667	·041494	·041322	·041152	·040984	·040816	·040650	·040486	·040323	·040161	24
25	·040000	·039841	·039683	·039526	·039370	·039216	·039062	·038911	·038760	·038610	25
26	·038462	·038314	·038168	·038023	·037879	·037736	·037594	·037453	·637313	·037175	26
27	·037037	·036900	·036765	·036630	·036496	·036364	·036232	·036101	·035971	·035842	27
28	·035714	·035587	·035461	·035336	·035211	·035088	·034965	·034843	·034722	·034602	28
29	·034483	·034364	·034247	·034130	·034014	·033898	·033784	·033670	·033557	·033445	29
30	·033333	·033223	·033113	·033003	·032895	·032787	·032680	·032573	·032468	·032362	30
31	·032258	·032154	·032051	·031949	·031847	·031746	·031646	·031546	·031447	·031348	31
32	·031250	·031153	·031056	·030960	·030864	·030769	·030675	·030581	·030488	·030395	32
33	·030303	·030211	·030120	·030030	·029940	·029851	·029762	·029674	·029586	·029499	33
34	·029412	·029326	·029240	·029155	·029070	·028986	·028902	·028818	·028736	·028653	34
35	·028571	·028490	·028409	·028329	·028249	·028169	·028090	·028011	·027933	·027855	35
36	·027778	·027701	·027624	·027548	·027473	·027397	·027322	·027248	·027174	·027100	36
37	·027027	·026954	·026882	·026810	·026738	·026667	·026596	·026525	·026455	·026385	37
38	·026316	·026247	·026178	·026110	·026042	·025974	·025907	·025840	·025773	·025707	38
39	·025641	·025575	·025510	·025445	·025381	·025316	·025253	·025189	·025126	·025063	39
40	·025000	·024938	·024876	·024814	·024752	·024691	·024631	·024570	·024510	·024450	40
41	·024390	·024331	·024272	·024213	·024155	·024096	·024038	·023981	·023923	·023866	41
42	·023810	·023753	·023697	·023641	·023585	·023529	·023474	·023419	·023364	·023310	42
43	·023256	·023202	·023148	·023095	·023041	·022989	·022936	·022883	·022831	·022779	43

RECIPROCALS OF NUMBERS—*continued.*

No.	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	No.
44	·022727	·022676	·022624	·022573	·022523	·022472	·022422	·022371	·022321	·022272	44
45	·022222	·022173	·022124	·022075	·022026	·021978	·021930	·021882	·021834	·021786	45
46	·021739	·021692	·021645	·021598	·021552	·021505	·021459	·021413	·021368	·021322	46
47	·021277	·021231	·021186	·021142	·021097	·021053	·021008	·020964	·020921	·020877	47
48	·020833	·020790	·020747	·020704	·020661	·020619	·020576	·020534	·020492	·020450	48
49	·020408	·020367	·020325	·020284	·020243	·020202	·020161	·020121	·020080	·020040	49
50	·020000	·019960	·019920	·019881	·019841	·019802	·019763	·019724	·019685	·019646	50
51	·019608	·019569	·019531	·019493	·019455	·019417	·019380	·019342	·019305	·019268	51
52	·019231	·019194	·019157	·019120	·019084	·019048	·019011	·018975	·018939	·018904	52
53	·018868	·018832	·018797	·018762	·018727	·018692	·018657	·018622	·018587	·018553	53
54	·018519	·018484	·018450	·018416	·018382	·018349	·018315	·018282	·018248	·018215	54
55	·018182	·018149	·018116	·018083	·018051	·018018	·017986	·017953	·017921	·017889	55
56	·017857	·017825	·017794	·017762	·017731	·017699	·017668	·017637	·017606	·017575	56
57	·017544	·017513	·017483	·017452	·017422	·017391	·017361	·017331	·017301	·017271	57
58	·017241	·017212	·017182	·017153	·017123	·017094	·017065	·017036	·017007	·016978	58
59	·016949	·016920	·016892	·016863	·016835	·016807	·016779	·016750	·016722	·016694	59
60	·016667	·016639	·016611	·016584	·016556	·016529	·016502	·016474	·016447	·016420	60
61	·016393	·016367	·016340	·016313	·016287	·016260	·016234	·016207	·016181	·016155	61
62	·016129	·016103	·016077	·016051	·016026	·016000	·015974	·015949	·015924	·015898	62
63	·015873	·015848	·015823	·015798	·015773	·015748	·015723	·015699	·015674	·015649	63
64	·015625	·015601	·015576	·015552	·015528	·015504	·015480	·015456	·015432	·015408	64
65	·015385	·015361	·015337	·015314	·015291	·015267	·015244	·015221	·015198	·015175	65

RECIPROCALS OF NUMBERS—*continued.*

No.	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	No.
66	·015152	·015129	·015106	·015083	·015060	·015038	·015015	·014993	·014970	·014948	66
67	·014925	·014903	·014881	·014859	·014837	·014815	·014793	·014771	·014749	·014728	67
68	·014706	·014684	·014663	·014641	·014620	·014599	·014577	·014556	·014535	·014514	68
69	·014493	·014472	·014451	·014430	·014409	·014388	·014368	·014347	·014327	·014306	69
70	·014286	·014265	·014245	·014225	·014205	·014184	·014164	·014144	·014124	·014104	70
71	·014085	·014065	·014045	·014025	·014006	·013986	·013966	·013947	·013928	·013908	71
72	·013889	·013870	·013850	·013831	·013812	·013793	·013774	·013755	·013736	·013717	72
73	·013699	·013680	·013661	·013643	·013624	·013605	·013587	·013569	·013550	·013532	73
74	·013514	·013495	·013477	·013459	·013441	·013423	·013405	·013387	·013369	·013351	74
75	·013333	·013316	·013298	·013280	·013263	·013245	·013228	·013210	·013193	·013175	75
76	·013158	·013141	·013123	·013106	·013089	·013072	·013055	·013038	·013021	·013004	76
77	·012987	·012970	·012953	·012937	·012920	·012903	·012887	·012870	·012853	·012837	77
78	·012821	·012804	·012788	·012771	·012755	·012739	·012723	·012706	·012690	·012674	78
79	·012658	·012642	·012626	·012610	·012594	·012579	·012563	·012547	·012531	·012516	79
80	·012500	·012484	·012469	·012453	·012438	·012422	·012407	·012392	·012376	·012361	80
81	·012346	·012330	·012315	·012300	·012285	·012270	·012255	·012240	·012225	·012210	81
82	·012195	·012180	·012165	·012151	·012136	·012121	·012107	·012092	·012077	·012063	82
83	·012048	·012034	·012019	·012005	·011990	·011976	·011962	·011947	·011933	·011919	83
84	·011905	·011891	·011876	·011862	·011848	·011834	·011820	·011806	·011792	·011779	84
85	·011765	·011751	·011737	·011723	·011710	·011696	·011682	·011669	·011655	·011641	85
86	·011628	·011614	·011601	·011587	·011574	·011561	·011547	·011534	·011521	·011507	86
87	·011494	·011481	·011468	·011455	·011442	·011429	·011416	·011403	·011390	·011377	87

Reciprocals of Numbers—*continued.*

No.	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	No.
88	·011364	·011351	·011338	·011325	·011312	·011299	·011287	·011274	·011261	·011249	88
89	·011236	·011223	·011211	·011198	·011186	·011173	·011161	·011148	·011136	·011123	89
90	·011111	·011099	·011086	·011074	·011062	·011050	·011038	·011025	·011013	·011001	90
91	·010989	·010977	·010965	·010953	·010941	·010929	·010917	·010905	·010893	·010881	91
92	·010870	·010858	·010846	·010834	·010823	·010811	·010799	·010787	·010776	·010764	92
93	·010753	·010741	·010730	·010718	·010707	·010695	·010684	·010672	·010661	·010650	93
94	·010638	·010627	·010616	·010604	·010593	·010582	·010571	·010560	·010549	·010537	94
95	·010526	·010515	·010504	·010493	·010482	·010471	·010460	·010449	·010438	·010428	95
96	·010417	·010406	·010395	·010384	·010373	·010363	·010352	·010341	·010331	·010320	96
97	·010309	·010299	·010288	·010277	·010267	·010256	·010246	·010235	·010225	·010214	97
98	·010204	·010194	·010183	·010173	·010163	·010152	·010142	·010132	·010121	·010111	98
99	·010101	·010091	·010081	·010070	·010060	·010050	·010040	·010030	·010020	·010010	99
100	·010000	·009990	·009980	·009970	·009960	·009950	·009940	·009930	·009921	·009911	100

Any sum multiplied by the reciprocal of a number is equal to the same sum divided by the number which the reciprocal represents. Reciprocals are frequently useful for facilitating hasty calculations; the reciprocal, used as a multiplier, being substituted for its number used as a divisor.—In the Table the reciprocals are those of integers and decimals mixed; but it is easy to extend their use to integers alone, or decimals alone, by adding to the reciprocal in the Table a decimal point for each integer added to its number, or deducting a decimal point for each integer subtracted from its number.

Thus, reciprocal of 20·9 = ·047847; of 209·0 = ·0047847; of 2090·0 = ·00047847.
" 0·209 = 4·7847; ·0209 = 47·847; ·00207 = 478·47.

SUPPLEMENT.

Electric Lighting.

Plain glass	absorbs	from	10 to 20	p. c.	of the	light
Ground	,,	,,	30 ,, 35	,,	,,	
Thin opal	,,	,,	40 ,, 50	,,	,,	
Ordinary opal	,,	,,	60 ,, 65	,,	,,	

Work, etc., in Lighting.

r_1 = Resistance of lamp in ohms.
r_2 = ,, ,, armature ,,
r_3 = ,, ,, wires and connections.
R = Total resistance in circuit $= r_1 + r_2 + r_3$
E = Electromotive force in volts = C R.
C = Intensity of current—Ampères

$$= \frac{E}{R} = \sqrt{\frac{746\ F}{R}} = \sqrt{\frac{746\ HP.\ D}{R}}.$$

F = Power absorbed in electrical work $= \frac{C^2 R}{746}$

= HP D.

HP = Actual horse-power to work Dynamo.

e = Efficiency $= \frac{D - (r_1 + r_3)}{R}$.

D = Duty $= \frac{F}{HP}$.

H = Heat developed $= C^2 R = \frac{E^2}{R} = E C.$

$= \cdot 2406\ C^2 R$ Calories (g. d. C.)

Resistance of Cylindrical Carbons per Metre. (Joubert.)

Diameter, mm.	1	2	3	4	5	6	10	15	20
Resistance, ohms	50·	12·5	5·55	3·125	2·	1·39	·5	·222	·125

ELECTRIC LIGHTING—*continued.*

ELECTRICAL UNITS.

			Symbol
Electro-motive force	Volt	$= 10^8$ C.G.S. units $=$ CR	E
Resistance	Ohm*	$= 10^9$ „ $= \frac{E}{C}$.	R
Current ..	Ampère†	$= 10^{-1}$ „ $= \frac{E}{R} = \sqrt{\frac{W}{R}}$	O
Heat ..	Joule	$= 10^7 = EC = C^2 R = \frac{E^2}{R}$.	J
Work ..	Watt‡	$= 10^7 = \cdot 00134$ HP $= C^2 R$.	W
Quantity.	Coulomb†	$= 10^{-1}$	Q
Capacity.	Farad	$= 10^{-9}$	q
Heat ..	Calorie	$4 \cdot 16 \times 10^7 = \cdot 004$ 76° F.	g.d.C.
Horse-power, English,		$=$ 746 Watts $= 746 \times 10^7$ C.G.S. units	HP
Time ..	Seconds	.. ..	t

$$C = \frac{E}{R} = \sqrt{\frac{W}{R}}; \; E = CR; \; R = \frac{E}{C}.$$

$$J = C^2R = \frac{E^2}{R} = E\,C; \; W = C^2 Rt.$$

Ω = Megohm (or one million ohms).
ω = Ohm.
Γ = Ampère.
Υ = Miliampère (or $\frac{1}{1000}$ Ampère).

* The British Association ohm $= \cdot 9868 \times 10^9$ C.G.S. units. C.G.S. denotes the Centimetre-Gramme-Second System. 10^n denotes $1 + n$ cyphers; thus $10^3 = 1000$; 10^{-n} denotes 1 at the nth place of decimals; thus $10^{-3} = \cdot 001$. The prefix "Mega" denotes 1,000,000: "Micro" denotes $\frac{1}{1000000}$ or 10^{-6}.

† Formerly Weber. ‡ Or Volt-Ampère.

Contractions Adopted by Paris Conference, 1881.

LENGTH.	SURFACE.	SOLIDITY, &c.
km = kilometre m = metre dm = decimetre cm = centimetre mm = millimetre	km^2 = sq. kilometre m^2 = „ metre dm^2 = „ decimetre cm^2 = „ centimetre mm^2 = „ millimetre ha = hectare a = are	km^3 = cubic kilometre m^3 = „ metre dm^3 = „ decimetre cm^3 = „ centimetre mm^3 = „ millimetre
WEIGHT.	**WEIGHT (*continued*).**	**CAPACITY.**
t = tonne = 1000 kg q = quintal = 100 kg kg = kilogramme dkg = decagramme g = gramme	dg = decigramme cg = centigramme mg = milligramme	hl = hectolitre l = litre dl = decilitre cl = centilitre

Italic letters are used for these contractions, and no stop is to be used at the right of them. The contractions succeed the figures to which they refer, on the same line and after the last decimal place, when decimals are used.

Resistance of Metals.

R = Resistance of wire in ohms at 0° Centigrade.
r = Specific resistance of metal (see table below).
s = Cross-sectional area of wire centimetres.
d = Diameter of wire in centimetres.
L = Length " "
t = Temperature in degrees Centigrade.

$$R = \frac{r \times 10^{-6} L}{s} = \frac{r \times 10^{-6} L}{\frac{1}{4}\pi d^2}.$$

The ohm being 10^9 C. G. S. units, the expression 10^{-6} becomes 10^3, for the Centimetre Gramme Second (C. G. S.) System.

	Specific Resistance (r). 1 Centimetre Cube.	1 mm Diam. 1 metre Long.	Increased* Resistance per °C. at 20°.	Melting Point.
	Microhms.	Ohms.	Ohms.	Centigrade.
Silver, annealed ..	1·521	·01937	·00377	1000°
" hard drawn..	1·652	·02103	—	—
Copper, annealed ..	1·616	·02057	·00388	1050°
" hard drawn..	1·652	·02104	—	—
Gold, annealed ..	2·081	·02650	·00365	1250°
" hard drawn ..	2·118	·02697	—	—
Aluminium, annealed	2·945	·03751	—	600°
Zinc, compressed ..	5·689	·07244	·00365	450°
Platinum, annealed	9·158	·1166	—	1770°
Iron "	9·825	·1251	·0063	1500°
Nickel "	12·60	·1604	—	—
Tin, compressed ..	13·36	·1701	·00365	235°
Lead " ..	19·85	·2526	·00387	335°
Antimony, compressed	35·90	·4571	·00389	440°
Bismuth "	132·7	1·689	·00354	265°
Mercury, liquid ..	99·74	1·2247	·00072	−36·5°
2 Silver, 1 Platinum	24·66	·314	·00031	—
German silver.. ..	21·17	·2695	·00044	—
2 Gold, 1 Silver ..	10·99	·1399	·00065	—

* The specific resistance due to temperatures exceeding 0° Centigrade in very pure metals approximately $= r\,(1 + \cdot003824\,t + \cdot00000126\,t^2)$. The resistance of commercial metals is generally much greater than that of pure metals.

Increase of Resistance with Temperature.

R = Resistance at temperature t° Centigrade.
r = " " 0° "
t = Temperature in degrees Centigrade.
a and b = Coefficients.
$R = r\,(1 + a\,t \pm b\,t^2)$

values of a and b.

For pure metals	$a = +\cdot003824$;	$b = +\cdot00000126$.
" mercury	$a = +\cdot0007485$;	$b = -\cdot000000398$.
" German silver	$a = +\cdot004433$;	$b = +\cdot000000152$.
" platinum silver alloy	$a = +\cdot00031$;	—
" gold silver "	$a = +\cdot0006999$;	$b = -\cdot000000062$

Relative Resistance of Wires in Single Circuit.

d and d_1 = Relative diameter of wires.
S and S_1 = " cross sectional area of wires.
R and R_1 = " resistance of wires.
L and L_1 = " lengths.
H and H_1 = " heat developed.
r and r_1 = Specific reistance of wires.

$$\frac{R}{R_1} = \frac{r\,L\,d_1^2}{r_1\,L_1\,d^2} = \frac{r\,L\,S_1}{r_1\,L_1\,S} = \frac{H}{H_1}.$$

Compound Circuit.

$r_1, r_2, r_3, r_4,$ = resistances of wires.

R_2 = Resultant resistance of r_1 and $r_2 = \dfrac{r_1\,r_2}{r_1 + r_2}$.

R_3 = " " r_1, r_2, and $r_3 = \dfrac{R_2\,r_3}{R_2 + r_3}$.

R_4 = " " r_1, r_2, r_3, and $r_4 = \dfrac{R_3\,r_4}{R_3 + r_4}$.

ELECTRIC LIGHT CONDUCTORS.

SAFE CURRENT.

RULE OF FIRE RISK COMMITTEE, S. T. E.:—
1000 ampères per square inch of sectional area.

RULE OF CLARK, FORD AND CO.:—
1 ampère for every 10 lbs. of copper per mile.

JAMIESON'S RULE:—
1000 ampères per square inch of sectional area, and 1000 ohms resistance of insulator for every volt of electromotive force in the current.

PROFESSOR FORBES' RULE:—

C = Current in ampères.
d = Diameter of Conductor in centimetres.
D = " insulated cable in centimetres.
t = Excess of temperature of conductor above the air.
H = Coefficient of radiation and convection = ·0003.
R = Specific electrical resistance of material.
k = Heat conductivity of insulator.
= ·00018 for guttapercha; = ·00041 for indiarubber.

$$C = \sqrt{d^3 t \frac{\pi^2 H}{4 R \cdot 24}}, \text{ for bare overhead wires.}$$

$$= \sqrt{\frac{\pi^2 k d^2}{\cdot 48 R} t \times \frac{3 D}{10 + 3 D \log_\epsilon \frac{D}{d}}} \Bigg\} \text{ for aerial insulated cables.}$$

For underground conductors (2 feet below the surface) a flat copper conductor 1 centimetre thick and 2,800 centimetres broad, would carry a current of 700·00 ampères with a rise of 10° C. in temperature; but the cost of copper is so great that large conductors of this kind should be of iron instead of copper.

COILS OF A DYNAMO.

S = The surface radiating heat.
r = The resistance of the coils.
C = Safe current which can be carried with a rise of 50° C.

$$C = \cdot 25 \sqrt{\frac{S}{r}}.$$

This does not apply to armature coils, which are cooled by rapid rotation.

Heating of Wires (Forbes).

C = Current in ampères.
D = Diameter of wire in centimetres.
t = Excess of temperature of wire above air Centigrade.
E = Coefficient of radiation and convection
= ·000168 for bright, and ·00032 for blackened copper.
R = Specific resistance of material in ohms

$$= \cdot 000001642 \left(1 + \frac{\cdot 38\,t}{100}\right) \text{ for copper.}$$

$$= \cdot 00001985 \left(1 + \frac{\cdot 38\,t}{100}\right) \text{ for lead.}$$

$$C = \sqrt{D^3 t \frac{\pi^2 E}{\cdot 96\, R}} = \sqrt{\frac{10 \cdot 28\, D^3 t E}{R}}.$$

Current required to increase the Temperature of Bare Bright Copper Wire t° Centigrade above the Surrounding Air.

Temperature of the air assumed at 20° Centigrade.

Diameter of Wire.		Current in Amperes.				
Centimetres.	Inches.	$t = 1°$ C.	$t = 9°$ C.	$t = 25°$ C.	$t = 49°$ C.	$t = 91°$ C.
·1	·03937	1·0	3·0	4·8	6·5	7·9
·2	·07874	2·8	8·3	13·5	18·3	22·4
·3	·11811	5·2	15·3	24·9	33·5	41·2
·4	·15748	8·0	23·6	38·3	51·7	63·4
·5	·19685	11·1	33·0	53·5	72·2	88·6
·6	·23623	14·6	43·4	70·3	94·9	116
·7	·27560	18·5	54·6	88·7	119	147
·8	·31497	22·6	66·7	108	146	179
·9	·35434	26·9	79·6	129	174	214
1·0	·39371	31·5	93·3	151	204	251
2·0	·78742	89·2	264	428	577	709
3·0	1·18112	164·0	485	787	1061	1303
4·0	1·57483	252	746	1211	1633	2006
5·0	1·96854	353	1043	1692	2283	2802
6·0	2·36225	463	1371	2225	3000	3685
7·0	2·75596	584	1728	2803	3781	4642
8·0	3·14966	714	2110	3422	4620	5671
9·0	3·54337	851	2519	4088	5511	6769
10·0	3·93708	997	2950	4788	6455	7926
Centimetres.	Inches.	$t = 1°{\cdot}8$ F.	$t = 16°{\cdot}2$ F.	$t = 45°$ F.	$t = 88°{\cdot}2$ F.	$t = 145°{\cdot}8$ F.

For *blackened* wire multiply the results above given by 1·3845.

A more powerful current might be used for a short interval.

HEATING OF INSULATED CABLES. (Forbes.)

d = Diameter of the conductor, centimetres.
D = ,, ,, cable or insulator.
K = Thermal conductivity of insulator
= ·00048 for guttapercha.
E = Coefficient of cooling = ·0003.
t = Excess temperature above surrounding medium, whether air or water, Centigrade.
R = Specific resistance of conductor ohms.
C = Current in ampères.

$$C = \sqrt{\frac{\pi^2 d^2 K t}{\cdot 48 R} \times \frac{3 D}{10 + 3 D \log_e \frac{D}{d}}}.$$

TABLE OF CURRENT REQUIRED TO HEAT INSULATED CONDUCTORS.

$\frac{D}{d}$ assumed = 4. Temperature of air, 20° Centigrade.

Diam. of Conductor.		Current in Ampères.				
Centimetres.	Inches.	t = 1° C.	t = 9° C.	t=25° C.	t=49° C.	t=81° C.
·1	·039	3·7	11·0	17·8	24·0	29·5
·2	·079	9·1	27·0	43·8	59·0	72·5
·3	·118	15·0	44·4	72·1	97·3	119
·4	·157	21·2	62·5	102	137	168
·5	·197	27·4	81·0	131	177	218
·6	·236	33·7	100	164	219	268
·7	·276	40·1	119	192	259	319
·8	·315	46·4	137	223	301	369
·9	·354	52·9	157	253	342	420
1·0	·394	59·3	175	285	384	472
2·0	·787	124	367	595	803	988
3·0	1·181	189	559	908	1225	1503
4·0	1·575	254	753	1221	1646	2021
5·0	1·969	319	945	1534	2068	2523
6·0	2·362	385	1138	1846	2491	3058
7·0	2·756	450	1330	2158	2846	3575
8·0	3·150	514	1525	2472	3335	4094
9·0	3·543	580	1716	2785	3755	4611
10·0	3·937	645	1909	3097	4178	5130

If K should = ·0003 instead of ·00048, as calculated, the results must be multiplied by a factor varying from ·95 when d = ·1; to ·84 for 1·0; and to ·78 for 10·0.

Heating of Coils. (Forbes.)

r = Resistance of coil in ohms when hot.
= 1·2 resistance cold at 50° Centigrade.
t = Permissible rise in temperature; say 50° Centigrade.
S = Surface of coil exposed to air in cm^2 (sq. centimetres).
E = Coefficient of cooling = ·0003.
H = Heat generated = $\cdot 24\, C^2 r$;
L = Heat radiated = $E\,t\,S$;
C = Current in ampères.

$$H = L; \quad \therefore \quad C = \sqrt{\frac{E\,t\,S}{\cdot 24\, r}} = \cdot 25 \sqrt{\frac{S}{r}};$$

Heating of Buried Conductors. (Forbes.)

b = Breadth of conductor 1 centimetre thick.
d = Depth below surface of ground, centimetres.
t = Temperature of conductor above that of the ground (C°).
t_1 = Temperature of ground above that of the air (C°).
C = Current in ampères.
K = Coefficient of conductivity = ·004.
R = Specific resistance of conductor, ohms.

H = Heat generated per centimetre, length = $\dfrac{\cdot 24\, C^2 R}{b}$.

L = Heat radiated = $E\,b\,t_1$.
E = Coefficient of cooling = ·0003.
l = Heat conducted.

$$H = L; \ \therefore C = \sqrt{\frac{b^2 t_1}{800\,R}}; \ \text{if } t_1 = 10°, \ C = \sqrt{\frac{b^2}{80\,R}};$$

$$l = \frac{K\,b\,t}{d} = \frac{\cdot 004\, b\, t}{d} \text{ and } H = l$$

$$\therefore \ C^2 = \frac{\cdot 004 b^2 t}{\cdot 24\, R\, d} = \frac{b^2}{80\,R}; \ \text{and } \frac{\cdot 004\, t}{\cdot 24\, d} = \frac{1}{80},$$

and $t = \cdot 75\, d = 45°$ C. when $d = 60$ centimetres.

Assuming 50° as permissible rise of temperature and 15° as the temperature of the air, $R = \cdot 2031 \times 10^{-6}$ ohms for copper

$$C = \frac{b \times 10^3}{\sqrt{162 \cdot 48}} = 25\, b.$$

Table calculated on the above assumptions for flat copper conductors buried at a depth not exceeding 2 feet or 60 centimetres below the surface.

b =	10	40	90	160	360	2,800	centimetres.
C =	250	1000	2250	4000	9000	70,000	ampères.

Buried conductors should be in the form of flat sheets.

PERFORMANCE OF MACHINES SUPPLYING ARC-LAMPS. (Hospitalier.)

	—	Continuous Current.					Alternating Current.		
	Formulæ.	Gramme.	Siemens.	Burgin.	Siemens.	Brush.	Meritens.	Meritens.	Siemens.
Number of lamps	n	1	1	3	5	16	1	5	12
Revolutions of generator ..	per min.	475	737	1535	826	770	870	874	620
Effective horse-power ..	T	16·13	4·44	5·32	5·05	13·39	11·7	12·28	16·39
Resistance of machine, ohms	—	·33	·66	2·8	7·05	10·55	—	—	—
„ of circuit without lamps	—	·1	·12	1·5	4·5	2·56	—	—	—
„ total in ohms	R	·43	·78	4·3	11·55	13·11	—	·59	4·62
Current in ampères	C	109·2	35·0	18·5	10·0	10·0	—	—	—
Fall of potential at lamp volts	E	53·0	53·0	41·0	47·4	44·3	—	—	—
Work of entire circuit ..	$\frac{RC^2}{75g}$	6·97	1·29	2·0	1·57	1·79	—	—	—
Work of one lamp, HP. ..	$\frac{EC}{75g}$	7·87	2·52	1·027	·64	·6	—	—	—
Work of lamps in 1 circuit HP.	t	7·87	2·52	3·08	3·2	9·6	—	8·4	11·31
Total electric work, HP. ..	T′	14·84	3·81	5·08	4·77	11·39	—	10·5	15·26
Mean electromotive force ..	n E + RC	102	80	203	353	840	2	—	—
Diam. of carbons, *mm.* ..	—	20	18	13	10	11	23	20	10
Luminous intensity, horzntl.	Carcels	952	210	50	67	37	1034	130,171	44
„ „ maximum ..	„	1960	805	227	72	76	—	—	—
„ „ mean spherical	l	966	306	82	52	38	931	117,154	39
Total „ „	L = $n\,l$	966	306	246	260	608	931	733	468

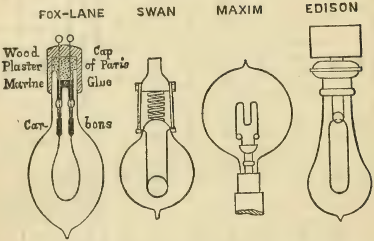
PERFORMANCE OF MACHINES SUPPLYING ARC-LAMPS—*continued.*

	—	Continuous Current.					Alternating Current.		
	Formulæ.	Gramme.	Siemens.	Burgin.	Siemens.	Brush.	Meritens.	Meritens.	Siemens
Number of lamps	n	1	1	3	5	16	1	5	12
Efficiency, total mechanical	$\frac{T'}{T}$	·92	·86	·95	·94	·85	—	·85	·93
„ mechanical of arcs	$\frac{t}{T}$	·43	·57	·58	·63	·72	—	·68	·69
„ electrical of arcs..	$\frac{t}{T'}$	·53	·66	·61	·67	·84	—	·8	·74
Carcels per electric HP. ..	$\frac{L}{T}$	65·1	80·3	48·4	54·6	53·4	79·6	59·7	33·3
„ „ mechanical HP.	$\frac{L}{T'}$	60·0	68·9	46·2	51·5	45·4	—	69·9	33·3
„ „ arc	$\frac{L}{t}$	128·8	121·4	79·9	81·3	63·3	—	87·3	41·4
„ „ ampère	$\frac{l}{C}$	8·85	8·74	4·43	5·2	3·8	—	3·59	3·66

MEAN EFFICIENCY OF CONTINUOUS CURRENT LAMPS WITH DIFFERENT MACHINES.

Formulæ.	$\frac{T'}{T}$	$\frac{t}{T}$	$\frac{t}{T'}$	$\frac{L}{T}$	$\frac{L}{T'}$	$\frac{L}{t}$	$\frac{l}{C}$
1 lamp (mean of 4 machines)	·89	·47	·53	55·	61·	113	8·1
2 to 5 lamps (mean of 5) ..	·86	·59	·70	60·	72·	102	6·6
10 to 40 „ (mean of 4) ..	·84	·70	·84	50·	59·	71	3·8
General (mean of 13) ..	·87	·59	·69	54·	63·	93	6·0

INCANDESCENT-LAMPS.



FOX-LANE LAMP. Filament of grass fibre, carbonised and enclosed in an exhausted globe.

SWAN LAMP. Filament of cotton immersed in sulphuric acid, then carbonised and enclosed in an exhausted globe.

MAXIM ,, Filament of cardboard, carbonised and enclosed in a globe in a rarefied atmosphere of benzoline.

EDISON ,, Filament of bamboo, carbonised and enclosed in an exhausted globe.

Electric Lighting.

TRIAL OF INCANDESCENT LAMPS. (Paris Exposition, 1881.)

	Edison.		Swan.		Fox-Lane.		Maxim.	
	At 16.	At 32.	At 16.	At 32.	At 16.	At 32.	At 16.	At 32.
Candles..	15·38	31·11	16·61	33·21	16·36	32·71	15·96	31·93
Ohms	137·4	130·0	32·78	31·75	27·40	26·59	41·11	39·60
Ampères	·651	·759	1·471	1·758	1·593	1·815	1·380	1·578
Watts	57·98	94·88	69·24	94·88	69·53	87·65	78·05	98·41
Volts	89·11	98·39	47·3	54·21	43·63	48·22	56·49	62·27
Kilogrammetres..	5·91	7·60	7·06	9·67	7·09	8·94	7·94	10·03
Lamp, per horse-power ..	12·73	9·88	10·71	7·90	10·61	8·47	9·48	7·50
Candles, ,, ..	196·4	307·3	177·9	262·5	173·6	276·9	151·3	239·4

The maximum efficiency of lamps of this character does not exceed 300 candle-lights per horse-power.

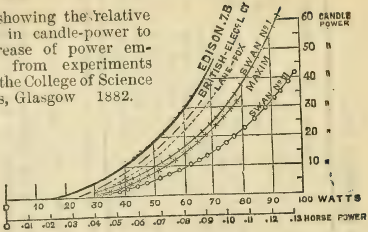
The economy is greater at high than at low incandescence; and the economy of light-production is greater in high than in low-resistance lamps.

The relative efficiency in Carcel burners of 7·4 candles at 16 candles is—Edison, 26·5; Swan, 24; Fox-Lane, 23·5; Maxim, 20·4. At 32 candles—Edison, 41·5; Fox-Lane, 37·4; Swan, 35·5; Maxim, 32·4.

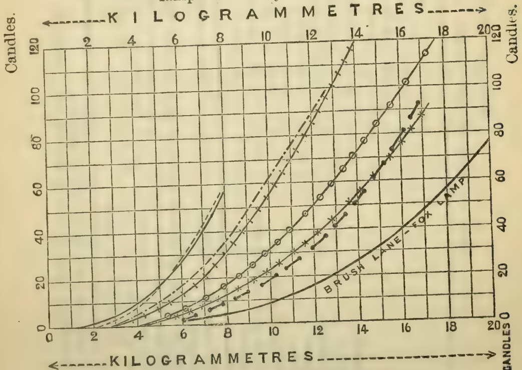
To double the light the current-energy was increased for Fox-Lane and Maxim 26 per cent.; for Edison, 28; and for Swan, 37 per cent.

Resistance of Lamp cold:—Edison, 241; Swan, 59; Fox-Lane, 55; Maxim, 72.

DIAGRAM showing the relative increase in candle-power to the increase of power employed; from experiments made at the College of Science and Arts, Glasgow 1882.



INCANDESCENT LAMPS.—Results of the tests of different lamps in the Crystal Palace.



Swan 12-candle lamp . .
Swan high-resistance lamp
Edison B. 8-candle ,,
Swan 20-candle ,,
Maxim ,,
Edison 16-candle ,,
British incandescent ,,

LEAD OF BRUSHES IN ELECTRO-MOTORS. PERCENTAGE OF EFFICIENCY WITH DIFFERENT SPEEDS AND LEADS IN A 36 LB. AYRTON-PERRY MOTOR.

Angle of Lead.	Revolutions per Minute.							
	608	800	1000	1200	1400	1600	1800	2000
− 66°	25·8	29·0	29·9	30·3	29·4	28·1	26·5	24·6
− 51°	26·2	28·6	29·5	28·6	26·6	23·4	21·4	18·0
− 36°	24·9	26·0	26·3	25·6	24·2	22·0	18·9	14·8
− 21°	26·2	27·1	26·0	23·6	20·8	16·2	11·6	6·0
− 6°	22.6	25·4	24·0	21·2	17·0	12·0	5·8	—
+ 9°	20·3	20·6	19·8	17·9	14·0	8·0	·9	—
+ 24°	17·4	17·4	16·6	14·7	12·0	6·9	2·6	—
+ 39°	12·9	13·4	10·2	8·9	4·2	—	—	—

There is a certain speed for each lead beyond which the efficiency diminishes in proportion to the increase in speed.

EXPERIMENTS WITH ELECTROMOTORS. (Ayrton and Perry.)

Motor.	Weight of Motor.	Actual Horse-Power.	Revs. per Minute.	Efficiency.
	lbs.			
Griscom	2·5	0·015	2500	·13
Jablochkoff	20·9	0·0137	780	·0335
Gramme Armature	8·03	0·0625	2853	·199
Siemens Field	30·8	0·0738	2527	·289
Magnet.	30·8	0·120	4117	·226
Ayrton-Perry	37	0·3	2000	·34
" "	37	0·2	1570	·40
De Meritens	72	0·75	2000	·50
Siemens	519	4·96	906	·746
"	519	5·60	731	·714

The weight of the motor is the total weight complete, including the base plate. The horse-power is the actual HP. given out by the motor in each case.

In small motors the loss by electric resistance is great, whilst the loss by magnetic friction is small. In motors on the Gramme, Siemens, or Meritens principle the heating due to resistance is in excess. The loss due to magnetic friction is proportional to the square of the speed.

Secondary Batteries. (Aron.)

(1) Spongy lead precipitated from acetate of lead by zinc, and pressed into plates, becomes active at once, in the negative but not in the positive plate.

(2) Rolled lead can be coated with disintegrated lead by electrolysis when placed in dilute sulphuric acid, if 1 per cent. of nitric acid be mixed with the sulphuric acid.

(3) Positive plates of rolled lead become disintegrated to a depth of about half a millimetre; they should, therefore, be at least 2 mm. thick; connections 5 mm. thick, soldered on with tin solder.

(4) Coherent plates may be obtained by covering them with a mixture of red lead and collodion, which is a good conductor.

(5) If x = Calorific value of the chemical action on the Negative plate,
y = That on the Positive plate,
E = Electro-motive Force $= x + y$.
If $E = 1 \cdot 78$ Daniells = 86,230 units, $y = 9710$, and $x = 79{,}520$.

(6) Plumbic acid $Pb.O\,(OH)_2$ is formed at the positive plate.

(7) The specific gravity of the liquid increases on charging, and decreases in discharging, the difference amounting to $\frac{1}{10}$.

(8) It is undesirable to hinder the free circulation of the liquid.

(9) The capacity of a cell may amount to 3000 kilogram-metres of energy per kilogramme of gross weight; but only $50 \cdot 07$ grammes of the gross weight per kilogramme are really active.

(10) The cells with thin coatings hold their charge only a few days; a gradual discharge takes place, and the positive plate is covered with lead sulphate; but with further formation the brown peroxide can be again produced.

The plates hold their charge better when dry.

(11) Plates with thick coatings at first keep their charge better, but afterwards fall off in storage capacity.

(12) A positive plate, prepared from lead sulphate, shows that oxidation only takes place at the parts which are in immediate contact with the lead plate, so that the lead sulphate is converted into lead peroxide, but only in the immediate neighbourhood of the lead plate, and not throughout the mass.

Abstract of Rules for the Prevention of Fire-risks from Electric Lighting.

Dynamo Machine.

(1) Fixed in a dry place.
(2) Not exposed to dust or flyings.
(3) Kept perfectly clean and bearings well oiled.
(4) Perfect insulation of coils and conductors.
(5) Fixed if practicable on insulating bed.
(6) Conductors firmly supported, well insulated, convenient for inspection, and marked or numbered.

Wires.

(7) Switches and commutators constructed so that when moved and left to themselves they cannot permit of a permanent arc or heating, and their stands to be of slate, stoneware, or other incombustible substance.

(8) Main circuit furnished with fusible safety-catch.

(9) Wires properly proportioned to current and changes of circuit from larger to smaller, protected with safety-catches, which fuse if any portion of the conductor exceeds 150° Fahr. Safety-catches enclosed in incombustible cases. If wires are perceptibly warmed by the ordinary current, it is a proof that they are too small and should be replaced.

(10) Complete metallic circuits should be used. Gas or water pipes for completing the circuit inadmissible.

(11) Bare wires out of doors on insulating supports should be coated with insulating material at least 2 feet each side of support.

(12) Bare wires over tops of houses at least 7 feet clear of any part of the roof. When crossing thoroughfares high enough to allow fire escapes to pass.

(13) Joints must be electrically and mechanically perfect. Good forms of joint are shown in the annexed diagram, whipped with fine wire and united with solder.

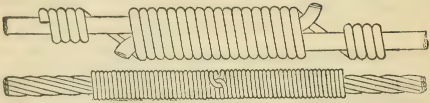
(14) The position of underground wires indicated, and easy of inspection and repairs.

(15) In-door wires efficiently insulated.

(16) Wires passing through partitions, &c., or liable to touch metallic masses, should be protected from abrasion or rats, if necessary by hard casing.

(17) In-door wires under floors or out of sight, protected from injury, and position indicated. Frequent testing is desirable.

Electrical Joints.



The joint is whipped with fine wire and united with solder.

Lamps.

(18) Arc lamps guarded by proper lanterns to prevent fall of incandescent particles. Globes protected with wire netting.

(19) Lanterns, and all parts handled, insulated from the circuit.

Danger to Persons.

(20) Conductors and fittings such that no one can be exposed to shocks of alternating currents exceeding 60 volts. There should never be a difference of potential exceeding 200 volts between two points in the same room.

(21) If the difference of potential in any house exceeds 200 volts, the house should be provided outside with a switch, so arranged that the supply can at once be cut off.

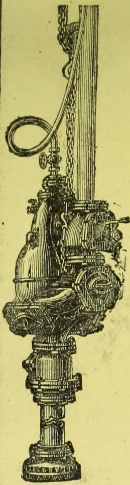
INDEX TO SUPPLEMENT.

SYNOPSIS OF CONTENTS.

(*For Index, see next page.*)

INDEX.

LONDON: PRINTED BY WILLIAM CLOWES AND SONS, LIMITED,
STAMFORD STREET AND CHARING CROSS.



PULSOMETER as used suspended in shaft up to 80 or 100 feet deep.

THE PULSOMETER (TRADE MARK.) PATENT STEAM PUMP.

12,000 IN USE.

Is specially suitable amongst other purposes for raising muddy and gritty water, and for use in difficult operations of all kinds.

A LARGE ASSORTMENT OF PULSOMETERS, BOILERS, PIPES, ETC., ON HIRE, WITH OPTION OF PURCHASE.

Size.	Size of Steam Pipe.	Size of Suction.	Size of Delivery.	Galls. per hour on 20 feet lift.	Price.	Price of Foot-valve.	Price of Pulsometer with Boiler and Pipes for 40 feet.
	In.	In.	In.		£	£ s.	£ s.
1	¼	1½	1	900	8	0 15	42 0
2	¼	2	1½	2,000	12	1 5	60 5
3	½	3	2	3,800	18	2 0	79 5
4	½	3½	2½	6,000	24	2 15	99 5
5	¾	4	3	10,000	32	3 5	119 18
6	1	4½	3½	13,000	42	4 0	145 0
7	1¼	5	4	17,000	55	4 10	On application.
7½	1¼	5	4	22,000	70	4 10	
8	1¼	6	5	28,000	80	6 0	
9	1½	7	6	40,000	100	9 0	
10	2	8	7	52,000	130	10 0	
11½	2	10	9	80,000	170	11 0	

Every Pump carefully tested on a high lift, and a record kept of its performance.

A LARGE STOCK KEPT OF DUPLEX AND DIRECT-ACTING PUMPS, CENTRIFUGALS, &c.

ICE-MAKING & COOLING MACHINERY.

FILTRATION, CEMENT MILL PLANT, PUMPING ENGINES.

ASK FOR LIST No. 9a.

PULSOMETER ENGINEERING Co., LIMITED,
Nine Elms Iron Works, London, S.W.